INEL

Idaho National Engineering Laboratory

FORM INEL-2631#
(Rev. 02-95)

Project File Number	
EDF Serial Number	ER-WAG7-85
Functional File Number	INEL-95/319

ENGINEERING DESIGN FILE

Project/Task OU7-13/14 Feasibility Study

Subtask In Situ Vitrification

EDF Page 1 of 99

TITLE: Digest of Reports and Information on Status of In Situ Vitrification Technology

SUMMARY

The summary briefly defines the problem or activity to be addressed in the EDF, gives a summary of the activities performed in addressing the problem and states the conclusions, recommendations, or results arrived at from this task.

This EDF contains the results of a review of information about In Situ Vitrification as a hazardous and mixed waste treatment technology. This information was acquired from a number of sources including application reports for the use of ISV at two Superfund Sites, a demonstration of ISV on a mixed TRU-contaminated site (Maralinga in Southern Australia) for the British Government at a nuclear weapons test range, and a large-scale treatability study for the treatment of radioactively contaminated soil planned for Seepage Pit 1 at ORNL in the spring of 1996. In order to address the status of current development work, principal investigators from both the INEL and PNL were queried about the applicability of ISV to treatment requirements for OU 7-13/14. Geosafe Corporation, the manufacturer and patent holder for the process, was requested to review the OU 7-13/14 waste characterization as it exists and comment on its adequacy to provide for an assessment of whether or not ISV could effectively remediate the waste. The results of this effort identify ISV as a strong potential remediation technology for major portions of OU 7-13/14 where the waste is well identified and where there is not buried waste that does not lend itself to a pre-conditioning step(s) that would insure complete remediation without the propagation of large gas releases and/or represent major obstacles to uniform vitrification.

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Distribution (summary page only):

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DIGEST OF REPORTS AND INFORMATION ON THE STATUS OF IN SITU VITRIFICATION TECHNOLOGY

1. INTRODUCTION

In Situ Vitrification (ISV) is an onsite thermal treatment technology for the treatment of soils and waste materials containing hazardous, radioactive, and mixed contaminants. The process involves the electric melting of soil or other earthen-like materials at very high temperatures that convert the soil and waste into a permanently immobilized vitrified product. The ISV technology is being applied commercially in the United States and abroad through Geosafe Corporation of Richland, Washington.

1.1 Purpose

The purpose of this Engineering Design File (EDF) is to provide evaluation information on In Situ Vitrification (ISV) as an Alternative Remediation Technology for the effective treatment of the buried waste contained in pits, trenches and soil vaults of the Subsurface Disposal Area (SDA) of the Radioactive Waste Management Complex (RWMC). This information, along with similar information on other Alternative Remediation Technologies, can then be used to perform a detailed analysis of alternatives in support of the OU 7-13/14 Remedial Investigation/Feasibility Study (RI/FS). The evaluation criteria requirements for this detailed analysis are provided in the guidance document for conducting the RI/FS by the U.S. Environmental Protection Agency (USEPA), report number; EPA/540/G-89/004. The specific statutory requirements for remedial actions that must be addressed in the Record of Decision (ROD) and supported by the FS report are listed below. Remedial actions must:

- Be protective of human health and the environment,
- Attain ARARs (or provide grounds for invoking a waiver),
- Be cost effective,
- Utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent possible, and
- Satisfy the preference for treatment that reduces toxicity, mobility, or volume as a principal element or provide an explanation in the ROD as to why it does not.

1.2 General Description of ISV

ISV is an innovative on site and in situ treatment process that involves the electric melting of contaminated-soil and/or other earthen materials for the purposes of permanently destroying, removing, and/or immobilizing hazardous and radioactive contaminants. ISV was invented by Battelle, Pacific Northwest Laboratory in 1980 for the U.S. Department of Energy (DOE) and was patented in 1983. The ISV technology is commercially available through Geosafe Corporation of Richland, Washington. (see Figure 1, page 4; Overall ISV System Schematic)

The process employs joule heating which refers to the utilization of the material being heated as the resistance element in an electric circuit. It operates by the insertion of a square array of four graphite or graphite/molybdenum composite electrodes into the ground to be remediated and applying an electrical potential to the electrodes to melt/vitrify the soil, debris and contaminants into a vitrified mass similar to volcanic obsidian at temperatures between 1600 to 2000 degrees centigrade. A pattern of electrically conductive graphite containing glass frit is placed on the soil in paths between the electrodes to initialize or promote the initialization of electrical conductance to vitrify the soil. The decision to use, and the selection of the amount of electrically conductive frit used, is a function of the soil type and the natural propensity of the soil to conduct electrical current.

A molten soil pool is formed on the surface of the treatment area. The continued application of energy results in the molten region growing deeper and wider until the desired treatment volume has been encompassed. The electrodes are allowed to progress down into the soil as it becomes molten, continuing the melting process to the desired treatment depth. When all of the soil within a treatment setting becomes molten, the power to the electrodes is discontinued. The electrodes are cut near the surface and allowed to settle into the molten soil to become part of the melt and the molten mass is allowed to cool. Upon cooling, the vitrified mass solidifies into a material similar in characteristics to volcanic obsidian.

This process is repeated in successive melts until the area is completely remediated. Multiple melts can be joined into a single, contiguous monolith. The high processing temperature (1600-2000°C) results in the complete destruction of organics from the treatment volume by vaporization followed by pyrolysis in the soil subsurface. No organics remain in the vitrified monolith because of the high temperatures involved. The gases move to the surface through the dry zone immediately adjacent to the melt, and through the melt itself. Gases at the surface are collected under a steel collection hood located above the treatment area and then treated in an offgas treatment system.

Most species of metals remain as oxides in the melt and are incorporated into the vitrified product upon cooling. ISV results in a 25-50% volume reduction for most soils, and even greater volume reduction for sludges and wastes that dewater and or decompose during processing. The volume reduction results in the creation of a subsidence volume or a dropping of the surface above the vitrified mass. In most treatment applications, the subsidence volume is filled with clean soil and the monolith is left in the ground since it no longer represents a hazardous concern.

The ISV treatment system consists of an electrical power transformer, an off-gas collection hood, an off-gas treatment system, the graphite electrode system, and a process control system. All equipment is trailer mounted except the off-gas hood system and the graphite electrode system which are transported to the site and assembled in place.

The off-gas hood is used to contain and direct all vapor and/or particulate emissions from the treatment zone into the gas treatment system and to support the graphite electrodes used in the melting process. The hood is a dome-shaped structure that completely spans and encompasses the area to be treated and extends beyond the actual treatment area radially to provide a positive safety margin to capture and channel all emissions that are generated. A low vacuum is maintained in the off-gas hood during operation to contain off-gases which are then vacuum conveyed to the off-gas treatment system.

The off-gas treatment system consists of a quencher, scrubber, demister, heater, particulate filter, activated carbon absorber, blower, and optional thermal oxidation unit. Other off-gas system treatment options can be added as needed. An electrical power transformer provides two-phase alternating current at the appropriate voltage and amperage to the electrodes. The entire ISV system is monitored from a process control room where electrode power consumption, off-gas temperature, hood vacuum, and other system parameters are tracked and monitored.

1.3 <u>Figure 1. Overall ISV System Schematic</u>

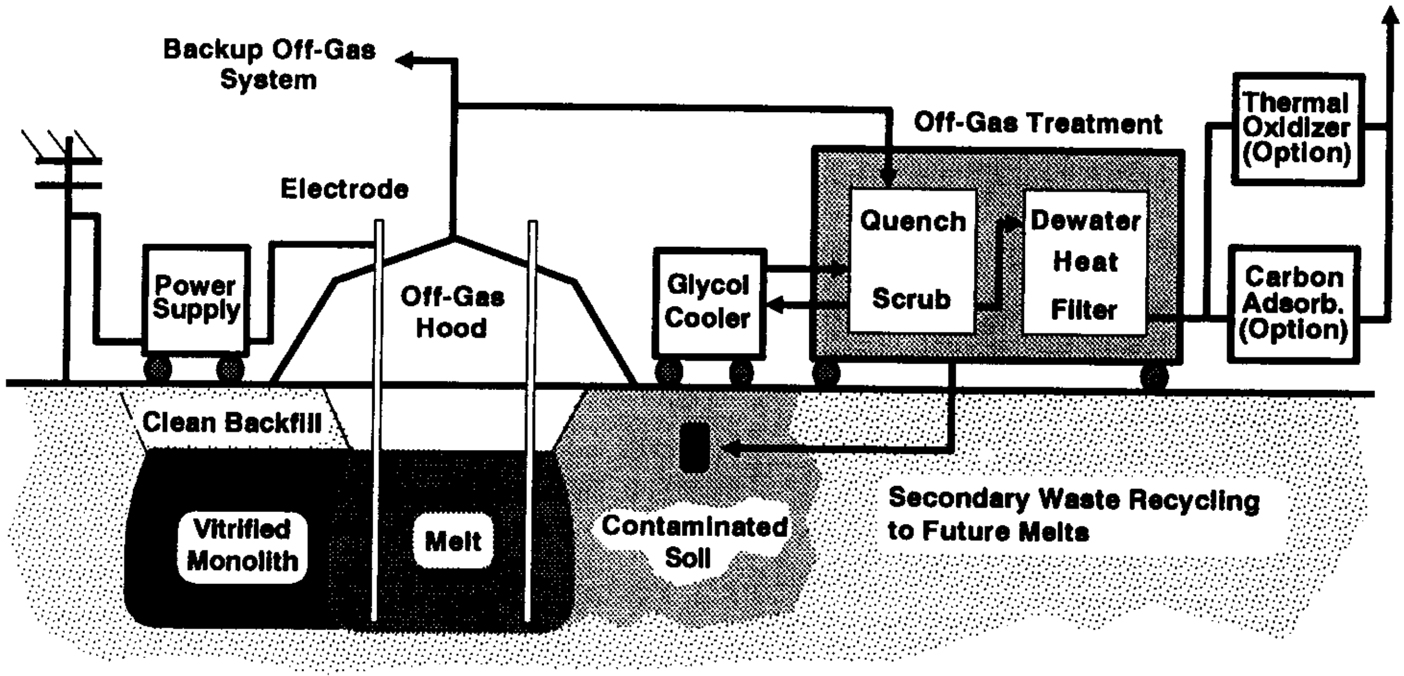


FIGURE 1. Overall ISV System Schematic

2. IN SITU VITRIFICATION TECHNOLOGY UPDATE

2.1 ORNL Large-Scale ISV Treatability Study[24,31]

A treatability study utilizing In Situ Vitrification (ISV) is planned to take place in early 1996 on Seepage Pit I at Waste Area Grouping (WAG) 7 at the Oak Ridge National Laboratory (ORNL) in support of an Interim Record of Decision (IROD) or removal action for closure of one or more of the seepage pits and trenches in early FY-1996. This study is the culmination of research and development efforts at ORNL for the application of ISV to highly radioactive contaminated soils.

The work is being funded by the U.S. DOE Office of Environmental Restoration (EM-40). The treatability study is a collaborative effort between Pacific Northwest Laboratory (PNL) and ORNL. Other collaborators for the overall work include Geosafe Corporation; Burtec, Inc.; RL Flowers & Associates, Inc.; 3M Corp.; and Battelle Memorial Institute.

This is a vitally important study for ORNL and a "Milestone Test" for ISV on a site contaminated with mixed fission products and transuranic isotopes. This treatability study is the result of the Remedial Investigation/Feasibility Study (RI/FS) for WAG 7 at ORNL which contains seven seepage pits and trenches. From 1951 through 1966 ORNL disposed of more than a million curies via liquid waste seepage into these pits and trenches. In the project description for this project it is stated that, "The present and potential mobility of radionuclides, particularly ^{90}Sr, into shallow groundwater and streams represents one of the most significant long term risks posed by ORNL waste management units."[24]

The rationale for selection of ISV in the treatability study was partially based upon the radiation fields at contact, which were estimated for exhumed waste of these pits and trenches to probably fall in the range of 200-1000 R/hr. It is further stated in the project description of the treatability study that, "Any exhumation approach entails a large risk for environmental releases because of the proximity to surface waters and the generally wet climate of the area. Such hazards, coupled with the lack of any credible alternative disposal site or method for exhumed waste, have focused consideration on in situ stabilization and closure techniques, particularly for high-radiation-hazard waste management units like the ORNL seepage pits and trenches."[24]

Key decisions that are cited in the treatability study design criteria are the following; "The success of ISV treatability study will lead directly to a proven and excellent technology to remedy most radioactively contaminated soil waste types. The key findings for this decision are successful and safe performance of ISV at the field scale and demonstration of a dramatic improvement in waste form from porous, leachable soil into monolithlic, unreachable rock or glass. After this study, the lingering stigma that ISV is still an unproven technology for radioactive soils can be removed."[24]

The performance criteria that the ISV treatability study will establish for field-scale technical performance are stated to be:

- Attaining the required depth, nominally 15 ft, to incorporate source contamination within and beneath the pits;
- Demonstrating field procedures for overlapping melt settings that are necessary to achieve fused melt segments;
- Demonstrating off-gas handling technology for accommodating and minimizing the volatilization of ^{137}CS;
- Demonstrating adequate site characterization techniques to predict ISV melting kinetics, processing temperatures, and product durability; and
- Promoting public acceptance of ISV technology by demonstrating its safety, implementability, site impacts, and air emissions and by coordinating the treatability study within the regulatory closure process. The format and content of this treatability study work plan follows regulatory agency guidance (U.S. EPA 1989).

This treatability study project will carry out the vitrification of 1000-1500 tons of radioactively contaminated soil in three melt settings within an old liquid waste seepage pit; titled pit 1. Pit 1 is an abandoned pit last used in 1951 which was filled with soil in 1981 and subsequently covered with an asphalt cap. It has continued to exhibit perched groundwater within 10 ft of the surface. Pit I is only a small problem in itself due to its limited size and radionuclide inventory ; about 38 Ci of ^{137}Cs and about 2 Ci ^{90}Sr with minor amounts (0.01 Ci each) of U and Pu isotopes and no nonradioactive organic or inorganic hazardous contaminants have been found. "Pit 1 is representative of six other seepage pits and trenches which are 5 to 10 times larger in size and contain much more significant radionuclide inventories, up to 200,000 Ci each. Remediation of these other pits by ISV represents a potentially feasible approach to minimize potential personnel exposures and hazards of environmental releases posed by alternative remedial actions such as exhumation or non in situ treatments."[24]

The project has the basic objectives to demonstrate that ISV can be carried out at the field scale to the geometric requirements of the ORNL seepage pits, can produce an excellent waste form, can be done safely with minimal secondary wastes, and can be performed with the required overlap of multiple melt settings. It is also being performed with high regulatory agency and public visibility to build the required support base for future use in ORNL remediation.

The project will also be testing several new off-gas handling techniques including a ceramic-fabric baghouse filter within the off-gas hood as well as an off-gas HEPA prefilter. The specifically-designed off-gas hood will have adjustable electrode spacing, an integral electrode hoist and feed systems, and an automotive capability for hood movement between melt settings without rigg support.

In the rationale report for justification of the ISV treatability study, the section referred to as "Key Decisions" states, " The success of this ISV treatability study will lead directly to a proven and excellent technology to remedy most radioactively contaminated soil waste types. The key findings for this decision are successful and safe performance of ISV at the field scale and demonstration of a dramatic improvement in waste form from porous, leachable soil into monolithic, unreachable rock or glass. After this study, the lingering stigma that ISV is still an unproven technology for radioactive soils can be removed."[24]

The project was initiated in November, 1992 and will be completed in March 1997 with the final treatability study report. The total project cost over this 4.5 year interval will be approximate $11 million.

The Pit 1 site characterization was completed in October 1994 and demonstrated in situ radioactively logging, employing driven pipes, as a facile method to establish ISV depth and lateral goals when confronted with an initially poorly defined contaminant distribution. Site preparations were completed April 1, 1995, and the receipt and initial setup of Battelle Pacific Northwest Laboratory's large-scale ISV equipment has been completed along with partial assembly of the new off-gas collection hood. A new off-gas collection hood was fabricated an arrived in August. Equipment assembly and site set up will be completed by February 1996 an the initial melt will start by March 1, 1996. Three large-scale overlapping melts are planned for March through May and should complete the vitrification of all the pit's source contamination.

Contact: Mr. Brian Spalding, Project Manager, ORNL (615) 574-726

2.2 Maralinga Site Phase 2 Demonstration[6]

The Maralinga Site is a former nuclear weapons test range, located in the State of South Australia, that was used by the British in the 1950's and early 1960's for above ground testing. Seven atomic explosions (major trials) during 1956 and 1957 resulted in fission product fallout. Several hundred ancillary experiments (minor trials) were carried out, some of which resulted in the explosive dispersal of plutonium, uranium and beryllium in the open environment. The Taranaki area of the Maralinga Site is the most contaminated area on the site. The ISV process was initially identified by the Commonwealth as the preferred alternative for stabilizing the Taranaki pits in the report by the Maratinga Technical Assessment Group. ISV was determined to be the leading candidate for this application because of the ability of the process to immobilize radionuclides in the vitrified product, the ability of the process to accommodate debris, the associated volume reduction, the ability of the process to destroy organic contaminants, and the improved occupational, public, and environmental safety benefits resulting from in situ treatment, Geosafe Corporation performed this work for the Australian Commonwealth under contract to the Department of Primary Industries and Energy (DPIE). Phase 2 of the project, which was completed in November, 1995, was designed to confirm the effectiveness of ISV on the actual soil and buried waste types existing at the site. The phase 2 process employed an intermediate scale (75kW) size equipment. Initial tests involved use of surrogates for the radionuclides of concern; the last two tests involved treatment of uranium (I kg each test) and plutonium (2 gm in last test) with the buried waste and debris materials. In addition to the incorporation of radionuclides, the tests involved very high quantities (37 wt%) of scrap metals. The overall project is to treat 21 burial pits at Maralinga's Taranaki Site after a successful phase 2 has been performed.

The results of phase 2 demonstration effort to date (see Appendix "A") are the following:

- The ISV process effectively treated the soil and debris combinations in the pits including the 37 wt% steel and other debris (barytes bricks, cable, lead, bitumen stabilized soil, and plastic).

- The voids and gas generating materials in the pits (carbonates, sulfates, and organics) did not pose any processing difficulties with respect to off-gas treatment or containment.

- Based on isokinetic off-gas sampling, the amount of uranium retained in the first demonstration melt exceeded 99.99%. Analyses for plutonium have not been completed but similar results are expected based on other testing.

- Following the demonstrations, health physics-related surveys of the equipment established that the insides of the off-gas containment hood, off-gas piping, and primary HEPA filters were free of detectable contamination above background levels. Consequently, decontamination of the equipment was not required.

- Based on preliminary gamma spectrometry analyses, convective currents in the melt resulted in the uniform distribution of the plutonium and uranium oxides within the vitreous phase in both melts.

- The target melt depth and width was exceeded, resulting in the complete treatment of the pit contents.

- The volume reduction for the soil and debris treated was 47% for the first demonstration melt and 55% for the second demonstration melt.

- The plutonium in the vitreous phase is not smearable. Significant intrusive sampling activities resulted in the creation and handling of many small fragments of vitrified product, including dusts, but did not result in the transfer of any detectable contamination to tools or personnel.

- The metal phase at the base of each melt was determined to be free of plutonium and uranium based on qualitative analyses. Quantitative analyses of the metal phase have not been completed.

Note: Quantitative analyses of the metal phase from the non-radioactive cerium demonstration established that cerium did not partition to the metal phase.

The conclusions of the phase 2 Maralinga site demonstrations are the following:

- The ISV process, at full-scale, can be expected to effectively treat the soil and debris combinations in the Taranaki pits.
- The data indicates that an ISV processing facility designed specifically for this application will be capable of handling the higher off-gas temperatures and transient off-gas flows associated with the treatment of the buried wastes.
- The vast majority of the plutonium will be retained in the melt (>99.99%).
- The vitrified product will be uniform, dense, hard product of high strength.
- The plutonium oxide will be effectively distributed throughout the main vitreous phase due to the convective currents that exist in the ISV melts.
- Plutonium will not be distributed to any significant extent to other phases in the melt (i.e., metal phase, porous cold cap, surface insulation).
- The ISV process can be safely applied to the materials present at the Taranaki site.

Phase 3 of the Maralinga ISV Project will consist of the detailed design and subsequent fabrication of the full-scale ISV facility to treat the 21 burial pits for the Taranaki area. These pits contain kilogram quantities of plutonium and uranium as well as other hazardous wastes and debris. The phase 3 effort should commence when the results are completed for phase 2 which is expected to occur in the very near future. Phase 4 will be carried out upon the completion of phase 3 and will consist of the actual remediation of the Maralinga site. The project collaborators include the Australia Nuclear Science and Technology Organization, AMEC-Mayfield, PNL, and Geosafe Corporation.

Contact: Mr. Leo Thompson, Project Manager, Geosafe Corp. (509) 375-0710

2.3 ORNL Buried Waste ISV Project[3]

The ISV process has been demonstrated on waste sites that contain buried debris but has not been applied successfully to buried waste sites containing intact, sealed containers such as drums. The presence of sealed containers is an issue due to the potential for transient events resulting from the sudden release of pressurized gases from the sealed containers. This project is currently evaluating a nonintrusive pretreatment method referred to as dynamic compaction whereby the integrity of the sealed container is compromised without making direct contact. This method is based upon engineering-scale testing that showed that a weakened container did not lead to a pressurization event. In this method, excessive void volumes are also removed by compacting the area to be treated with large weights dropped on the surface.

Geosafe has demonstrated an intrusive method described elsewhere in this report that breaches the containers by a method referred to as dynamic disruption.

In addition, processing of the containers from depth in a bottom up ISV approach (top down is conventional method employed) is also being evaluated. Funding for engineering-scale tests for these evaluations is being provided by EM-40 at ORNL. Work is scheduled for completion in FY-96.

Contact: Mr. Patrick Lowery, Project Manager, PNL (509) 373-0535

2.4 INEL Buried Waste ISV Project[24]

A collaborative effort between INEL and PNL between 1988 and 1992 evaluated ISV for buried waste applications at the INEL such as is found in OU 7-13/14. A comprehensive testing and analytical program was carried out which included a series of engineering-scale tests and two staged pilot-scale field tests. The results of this work showed the ISV process capable of treating buried waste material but required further engineering design and development work to address issues associated with sealed containers and melt kinetics that resulted in transient spikes in the off-gas hood pressure and temperature. Pressure surges were encountered that exceeded the pressure relief capacity of the pilot-scale off-gas hood (the hood was designed for soil-only applications). Significant issues were identified in this pilot-scale test; such as electrical instabilities, edge effects, and several other issues.

Much additional development work and actual remediation experience has occurred since this 1992. The issues identified by this project were used to target development needs addressed in the ISV Technology Development Plan for Buried Waste issued in July, 1992. The status of this development work that identifies the potential for employing ISV to meet the needs for OU 7-13/14 are discussed in more detail in Sections 3 and 4.

Contact: Mr. Richard Callow, Principal Investigator, INEL (208) 526-2042
Mr. Ja-Kael Luey, Technical Consultant, PNL (509) 376-5740

2.5 ISV Spot Melting Project[3]

Previous experience shows that the ISV process has a depth limitation of approximately 22 feet, although efficiency begins to drop off after about 18 feet. This on-going project addresses the depth limitation issue by evaluating methods to initiate and propagate the ISV process in the subsurface in order to effectively extend the depth treatment capability of ISV. This method makes provisions to allow for the selective treatment of concentrated waste locations at depths well below 18 feet. With this technique, researchers expect to demonstrate the ability to initiate an ISV melt at an underground location, thus addressing the depth limitation currently experienced by ISV during the traditional "top-down" technique. It also will provide a technique for installing a subsurface horizontal barrier. This project was funded by EM-40 to meet Hanford specific needs. The principle issue in the field involves how to deliver the conductive starter material to initiate the underground melt.

In FY-94, start-up methods were evaluated (via vendor surveys and laboratory testing). Directional drilling and pneumatic fracturing were selected methods to accomplish these provisions. An integration of pneumatic fracturing and in situ vitrification was carried out in a laboratory study for a Hanford application and proved to be a successful method of extending the ISV depth. This effort is ongoing. FY-95 pilot-scale results show the concept has promise but the start up method for Hanford soils needs additional work. Project collaborators include Underground Research, Inc.; Bechtel Hanford, Inc.; New Jersey Institute of Technology; Accutech Remedial Systems; and Golder Associates.

Contact: Mr. Ja-Kael Luey, Technical Consultant, PNL (509) 376-5740

2.6 Parsons Superfund Project[19]

Parsons Chemical Superfund Site in Grand Ledge, Michigan represented the first commercial application of ISV technology. The site involved 4,800 tons of silty clay soil contaminated with a variety of pesticides, heavy metals (mercury, lead, & arsenic), and trace amounts of dioxin. This application was performed by excavating the contaminated soil from various locations on the site and consolidating it into nine adjacent cells. Each cell was in a 16 ft. deep trench, was 26 ft. square, and was located in an open area of the site. A significant amount of debris from the site (including protective clothing, roots and vegetation, wood, plastic sheeting, drum lids, and tires) was also placed in the trench with the contaminated soil.

The project was completed and closed out in and reported on by the EPA SITE Demonstration Program. (See Appendix "B"). The SITE report concluded that the ISV technology performed well relative to all the critical demonstration objectives, and that ISV technology should be applicable to other sites with similar contaminants and soil conditions. Analyses of the vitrified monolith confirmed the complete absence of organic contaminants, and the secure immobilization of heavy metals (including mercury). Adjacent soil sampling was performed to assess whether or not any contaminants may have moved from the treatment volume into the adjacent soil during processing. All the adjacent soil sample results were nondetect for the target contaminants of concern.

Time of Performance: June 15, 1993 to May 27, 1994 (From mobilization to demobilization)

Client: U.S. EPA Region 5
77 West Jackson Blvd. HSE-5J
Chicago, IL 60604

Contact: Mr. Len Zintak, EPA Project Manager (312) 886-4246

2.7 Wasatch Superfund Project[19]

This Superfund Project employing ISV was completed near the end of October, 1995. The project involved treatment of contaminated earthen materials present in a 125 ft. by 125 ft. evaporation pond. It consisted of the treatment of 6,000 tons of heavily contaminated soil and debris at the Wasatch Chemical Superfund Site in Salt Lake City, Utah. The main contaminants of concern were dioxin, pentachlorophenol, xylene, chlordane, DDT, DDE, 2,4-D, and TCE. The project involved some staging of waste materials including soils and debris that were collected from around the site and placed on top of the evaporation pond materials for treatment. Thirty-seven melts were carried out in a 6 by 6 array with each melt carried out on a volume encompassed by 25 ft. by 25 ft by 8 ft. deep. A single large contiguous monolith was formed upon completion of the 37 melts. Two off-gas hoods were employed to simplify the logistical treatment needs and expedite the total remediation. All analyses to date indicate that the remediation was completely successful; the vitrified product contained no dioxins or organics and off-gas sampling taken during the liquid dioxin treatment period indicated that all contaminants (including dioxins, furans, PCBS, pesticides, herbicides, VOCS, and HCL) were below detection limits. Additional performance samples were recently acquired and analyses are currently ongoing. This treatment per Geosafe information represents a treatment of materials for which no other treatment or disposal means was available and as such, was a first for dioxin treatment worldwide.

Contact: Mr. Jim Hansen, VP, Bus. Dev'mt & Communications, Geosafe Corp.
(509) 375-0710

2.8 ISV of Low-Alkali Soils[3]

Previous attempts at using ISV to process soils depleted in the alkali and alkali-earth elements (i.e., Na and K), such as found at the DOE Savannah River Site and on the eastern seaboard of the United States have experienced difficulties in establishing and propagating the melt. This is the case since these elements provide a reasonable amount of electrical conductivity in the melt. Fluxants may be added to the soil to overcome this problem, but this introduces an additional step to the process and may increase the exposure potential of personnel to radioactive and/or hazardous contaminants during the site pretreatment. This project performed engineering-scale testing and found that by increasing the power density applied to the melt zone, these very low alkali soils could be vitrified with essentially no additional pre-processing steps. This project was funded by EM-50 and was completed in FY-94. It was performed in conjunction with SRS EM-40 personnel for evaluation as a remediation alternative for the L Area Oil and Chemical Basin.

Contact: Mr. Patrick Lowery, Project Manager, PNL (509) 373-0535

2.9 TSCA Operating Permit for PCB Treatment[19]

The U.S. Environmental Protection Agency (EPA) granted Geosafe's ISV technology a National TSCA Operating Permit in October of 1995. The permit allows Geosafe to apply ISV to soil and other solids contaminated with PCBs. Average concentrations of PCBs are limited to 14,700 ppm with hot spot concentrations up to 17,860 ppm in the Geosafe operating permit. This demonstration project was carried out in Spokane, Washington at a private Superfund site in EPA Region 10. Thirty-one hundred tons of contaminated soil and debris were treated in five contiguous melt settings that were staged for treatment in a 26-ft square, by 16-ft deep configuration. One treatment setting was spiked with PCBs to an average level of 14,700 ppm. The four remaining cells contained varying amounts of debris; one with 8 wt% concrete, another one with 11 wt % asphalt. Each of the four contained arrays of 20 steel drums holding PCB-contaminated soil and water. Prior to processing, the drums were treated in place by a vibratory beam technique which ruptured the drums so that water vapor could easily escape during processing. Test results showed conclusively nondetect levels for PCBs in the vitrified product and the stack gases and overall analytical results showed a system DRE of > 99.9999% for the ISV processing of PCBS. It is especially noteworthy that the vibratory beam technique was employed on the four cells containing drums as a means of breaching the drums in place. This method, demonstrated effectively here, is a recommended technique for pretreatment of buried waste which contains sealed containers. This demonstrated pretreatment technology makes ISV more attractive for potential applications at OU7-13/14.

Time of Performance: July 5, 1994 to October 31, 1994 (from mobilization to demobilization)

Client: Bechtel Environmental
50 Beale St.
San Francisco, CA 94116

Contact: Mr Russ Stenzel, Bechtel Project Manager (415) 768-3385

2.10 Soil Heating/ISV Option; Selected Best Alternative for Rocky Flats[9,31]

An Alternatives Analysis for source remediation at Trench T-3, Operable Unit No. 2 evaluated four alternatives for the treatment/disposal of waste from the T-3 trench in Operable Unit 2 (OU2) of Rocky Flats Environmental Technology Site (RFETS). Trench T-3 contains both organic and radionuclide contamination; the organic contamination exists as a non-aqueous phase liquid (NAPL) and dissolved in water perched in the trench. Analysis of the NAPL indicated approximately 37% diesel, 17% gasoline, 4% tetrachloroethylene (PCE), and 1% trichloroethylene (TCE), along with several other organics at lower concentrations. Radionuclide levels are relatively low at approximately 800,000 pCi/l for both gross alpha and beta.

The four alternatives for the proposed removal action options for the treatment/disposal of waste from the T-3 trench for source remediation are the following:

(1) Pump liquids/excavate solids/stabilize for transport/treat and dispose off-site;

(2) Pump liquids/excavate solids/treat and dispose on-site;

(3) In situ soil heating/in situ bioremediation/RCRA cap; or

(4) In situ soil heating/in situ vitrification (ISV).

These alternatives were selected through a consensus process, evaluating pros and cons, using the professional judgement and experience of project managers and technical support personnel familiar with Trench T-3 and a wide range of treatment technologies.

Process alternatives for source remediation at Trench T-3 were assessed for their abilities to meet a set of criteria based on CERCLA guidance (EPA 1988) which is the same criteria that is being employed for OU 7-13/14 at the INEL. These criteria as cited for this alternatives analysis are the following:

- Long-term effectiveness and permanence
- Ease of compliance with requirements
- Reduction of toxicity, mobility, or volume

- Short-term effectiveness
- Schedule
- Implementability
- Cost
- Sensitivity of treatment to waste form
- Leveraging for other contaminated sites at Rocky Flats

Based on the comparative analyses of the alternatives completed, the recommended remediation for Trench T-3 is Alternative #4. The waste in T-3 will be resistively heated in situ to remove volatile organic compounds, then ISV will be applied to the trench, destroying and/or removing the remaining heavy organic contaminants, and immobilizing the radionuclides. Alternative #4 was recommended because of its overall rating. It ranked highly in all criteria, better than the other alternatives in everything but cost and implementability, where it ranked second.

Subsequent to the Alternatives Analysis described above, an ISV Treatability Study on soil and waste from T-3 was carried out by Geosafe and EG&G of Rocky Flats. The specialized form of pretreatment identified for use with ISV for this application is PNL's six-phase soil heating process[34] which is planned to remove volatile liquids prior to heating and subsequent vitrification using ISV. It is believed that this combination of heating at much lower temperatures before applying ISV is a very positive means of pretreating to eliminate the potential for transient vapor surging where there are concentrations of VOCs present in the waste. There are a number of technologies that can preferentially remove volatile components before ISV is applied.

The overall ranking of the four alternative technologies resulted in a score of 37 out of a possible 45 for Alternative #4 followed by scores of 33 for Alternative #3, 25 for Alternative #2, and 26 for Alternative #1.
(See the Alternatives Performance Summary for this project in Appendix "C")

Contact: Mr. Jim McLaughlin, Project Manager, (Jim was the PM for this project in FY-95, when EG&G was the contractor for the O & M contract for Rocky Flats), (303) 966-6995
Mr. Matthew Haass, P.E., Sen. Proj. & Bus. Dev'mt Eng'r, Geosafe Corp. (509) 375-0710

2.11 ISV Japan, Limited[19]

ISV is now commercially available in Japan after ISV Japan Limited was formally established in the summer of 1995. Five major Japanese shareholder companies signed an agreement with Geosafe for licensing ISV technology products and services in Japan. These companies are: The Japan Research Institute, Mitsubishi Corporation, Ube Industries, Hazama Corporation, and Konoike Corporation. This agreement points toward Japan's rapidly growing environmental cleanup and waste treatment markets. It also would appear to identify ISV as a technology that Japan will benefit from internally.

Contact: Mr. Jim Hansen, VP, Bus. Dev'mt & Communications, Geosafe Corp.
(509) 375-0710

3. APPLICABILITY OF ISV TO OU 7-13/14[Appd. D]

3.1 Geosafe Corporation Assessment

Geosafe Corporation was requested by letter, dated September 11, 1995 to provide information on ISV and documentation to support their respective responses to a series of questions that were raised by the letter. A copy of the letter and Geosafe's responses in letters dated September 19 and October 23, 1995 are included in the Appendix "D." Also contained in Appendix "D" is additional information from Geosafe in a letter dated January 19, 1996. In Geosafe's initial response, of September 19, to the INEL request for information two common approaches to the application of ISV to buried waste are cited by Geosafe.

The approaches cited and their respective rationale are as follows; (1) in situ treatment, and (2) staged treatment in a waste cell. The application of in situ treatment requires a thorough characterization of wastes before treatment. Characterization needs can be reduced for some sites by pretreating the wastes using some specially developed techniques by Geosafe. Potentially, there are some waste forms that are not suitable for in situ treatment (i.e., pressure cylinders) and should be removed before processing with ISV. The second approach for employing ISV entails employing a staging methodology that calls for first staging the material in a waste cell and then processing with ISV. During the staging process, undesirable material can either be pretreated (i.e., crushed or shredded) or removed. Staging of material significantly reduces the amount of up-front characterization that must be done prior to remediation. Based on controlling the placement of material in the treatment cell, the performance of ISV can be estimated very accurately. Many waste forms that are not suitable for in situ treatment can be treated in a staged configuration if blended with other wastes.

The decision to treat wastes in situ or in a staged configuration is largely an economic consideration. There comes a point at which the cost of restaging material is less expensive than collecting detailed site characterization information. (See Figure 2, Page 21; Site Pre-Conditioning Logic for ISV Application to Buried Wastes).

The breakout of Geosafe Corporation's specific responses to ISV's potential applicability to OU 7-13/14 are presented below in question and answer format:

Question: Based on the attached waste/soil description, are there waste forms or types that could not be treated by your technology?

Answer: A general limitation of the ISV technology for treating buried wastes is that the material must be sufficiently characterized to ensure safe operation of the equipment. For example, ISV would not be recommended to process a burial trench if its contents were totally unknown. Specific waste form limitations for ISV are: (1) wastes must contain sufficient earthen material to form a satisfactory vitrified product, (2) sealed containers must be punctured, (3) large internal void spaces in the waste material must be collapsed or filled, and (4) the aggregate materials should contain less than 10 wt% organics.

The following pre-conditioning methods can be used to make buried wastes acceptable for ISV processing if the above limitations are not met. Sealed containers can be punctured with a steel beam that is vibrated into the ground. The vibrating beam will disrupt the integrity of containers thus making them acceptable for processing. Large void cavities can be filled with sand, grout or concrete or compacted to eliminate void space. Wastes which exceed the organic concentration limit may be processed if blended with other material or if modifications are made to the ISV processing equipment to increase its heat handling capacity.

Question: Based on the attached waste/soil description, are there pretreatment requirements such as sorting, sizing, separations, etc. in order to effectively utilize your technology to treat OU 7-13/14 waste? If so please describe.

Answer: As discussed above, the primary limitation of the ISV technology for treating buried wastes are sealed containers holding liquids. Burial trenches which have sealed containers of liquids can be pretreated by either puncturing the containers I situ or by excavating the containers and then restaging them. During the restaging process, the containers can be compacted by heavy equipment. Some large buried wastes (e.g., reactor core and other miscellaneous vehicles) may not be acceptable for ISV and need to be removed or size reduced before processing,

Question: Has your technology been used to remediate radioactive waste sites? If so, what are typical worker exposure rates? If not, please state how adaptable the technology would be to a radiation environment (feasibility of remote operation, reliability, maintenance requirements, etc.).

Answer: In 1983 Pacific Northwest Laboratories performed a pilot-scale test on plutonium contaminated soil that showed excellent results. Between 1986 and 1990 two large-scale ISV radioactive tests were performed at Hanford. The first test treated a portion of a TRU-contaminated drain field. This test was largely, successful; however, some equipment difficulties were encountered. The second test was conducted on a disposal crib (116-B-6A) which contained 1 curie of mixed fission products. This test showed no reportable exposure was encountered.

In November 1995, ISV is scheduled to treat a liquid disposal pit at Oak Ridge National Laboratory (Pit 1) which contains 10 curies of strontium and cesium. Geosafe completed intermediate-scale tests (4 to 6 ton melts) in October 1995 at the Maralinga Site in Australia. These tests demonstrated the effectiveness of ISV in treating uranium and plutonium in a complex soil mixture containing up to 37 wt% scrap metal.

Note: This cited demo at ORNL is now scheduled for spring, 1996.

ISV should be capable of processing material having a high associated radiation dose because of the following features:

- Requires minimal or no material handling
- Soil can be placed over a site to provide shielding
- Equipment is remotely operated during the melting process

In addition, many of the operation and maintenance items associated with the off-gas treatment system can be performed in a glove box type enclosure which lessens worker exposures.

3.2 Cognizant Reviewers Assessment

Personal discussions were held with cognizant engineers and/or scientists within the DOE national laboratory system to gain a more balanced and enlightened view of the applicability of ISV to OU 7-13/14. Included below are solicited input from selected cognizant personnel regarding ISV's applicability to OU 7-13/14 at the INEL.

3.2.1 Applicability Assessment by Mr. R. K. Farnsworth of LMIT at INEL

The ISV technology is estimated to be significantly less expensive than other remediation technologies in remediating transuranic buried waste sites within the DOE complex. Previous studies have shown that ISV is less expensive than standard "retrieve and treat" technologies. However, the application of ISV to buried waste sites has been hampered by a number of technical issues that have been perceived as insurmountable. There are two main issues; contaminant migration issue, and pressure build-up issue.

Note: In Section 4.7, General Cost Effectiveness, the previous studies addressing cost comparisons and reported cost effectiveness by Geosafe Corporation are discussed in detail.

3.2.1.1 Contaminant Migration Issue. In the discussion of this issue, it is stated that this issue is further broken down into the presence of semi-volatile compounds (those that vaporize at temps >100°C) and their potential migration and volatile compounds (those that vaporize at temps <100°C) and their potential migration. He further states that Geosafe test results show no net migration of semi-volatile contaminants and so the major issue is for the potential migration of volatiles vaporizing at less than 100°C. It is well established that technologies already exist for the removal of volatiles from the soil such as vapor vacuum extraction or steam-enhanced soil gas extraction

Note: In Section 2.10; the Rocky Flats Alterative Evaluation resulted in recommending ISV in combination with in situ soil heating.

3.2.1.2. Pressure Build-up Issue. In the discussion of this issue, two causes/sources are cited that can result in pressure build-up during ISV processing; the presence of sealed containers and/or large voids in the buried waste. The vibratory rod (also referred to as vibrating beam) method was used effectively by Geosafe during the remediation at Spokane, Washington to breach sealed drums during this remediation for PCB removal/treatment.

Another method that has shown positive results for reducing or potentially eliminating pressure build-up from occurring is the use of "Graphite Venting" during ISV processing. (See report titled, "The Effect of Graphite Venting on ISV Processing of Low Permeability Soils," by B.M. Gardner and R.K. Farnsworth.)

3.2.2 Applicability Assessment by Mr. Ja-Kael Luey of Battelle at PNL. Mr. Luey stated that there are many waste configurations at OU 7-13/14 where ISV technology can be deployed effectively to remediate. He cites four general waste configurations as targets for ISV deployment; (1) contaminated soil, (2) contaminated soil with debris, (3) buried waste- and (4) miscellaneous waste.

3.2.2.1 Contaminated Soil. The ISV technology is being applied commercially to treat soil contaminated with hazardous constituents. Correspondence with Geosafe Corporation indicate that full-scale remediation efforts involving mercury and volatile organics (such as trichloroethylene and tetrachloroethylene) did not result in the transportation of such species into the surrounding soil. In addition, Geosafe and PNL are working on projects that involve radioactively contaminated soils (Geosafe's project involves plutonium and uranium, PNL's project involves cesium and strontium). Typical site characterization needs include composition analysis of the soil, location of contamination, and any unique site geology.

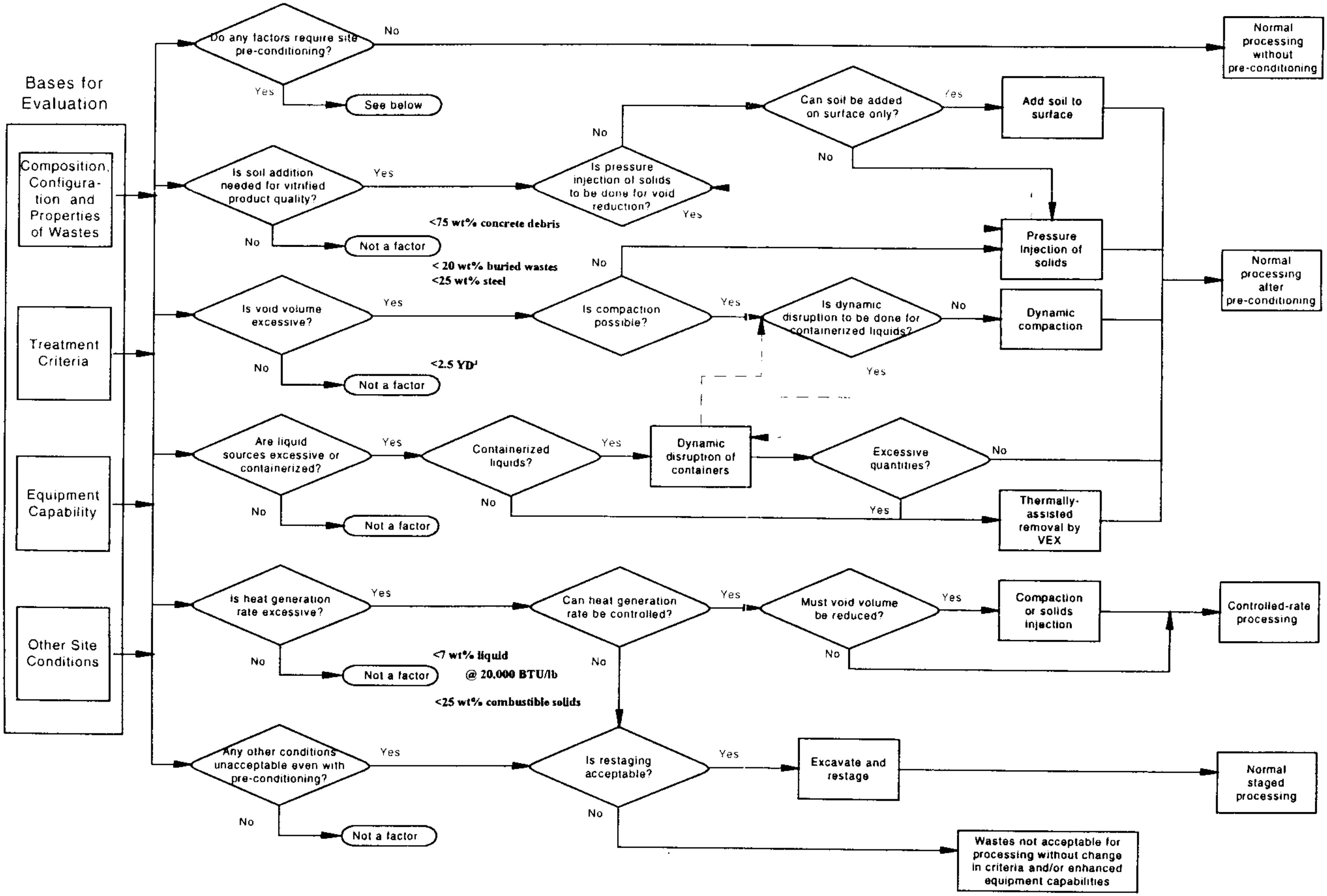
3.2.2.2 Contaminated Soil with Debris. Geosafe has been routinely applying ISV to contaminated soil sites that also contain debris. Types of debris include scrap metal, wood, paper, protective clothing, HEPA filters, tires, concrete, and plastic. Site characterization requirements are the same as for soil-only sites.

3.2.2.3 Buried Waste. ISV is applicable to buried waste; pretreatment is required for sites that contain sealed containers. Dynamic disruption employing the vibrating rod was successfully used by Geosafe to breach sealed containers that were in a known configuration. PNL has performed engineering scale studies that show dynamic compaction is another pretreatment method. Processing from depth (from the bottom to the surface) has been proposed as a means to treat buried waste without pretreatment. This technique has not been demonstrated in the field. Engineering-scale tests by PNL show this method may eliminate the expulsion of molten soil during an event (release of gases from a sealed container) but may not alleviate the pressurization associated with the event. Another option for treating buried waste would be to integrate ISV with ongoing retrieval operations. This reduces the problem to contaminated soil with debris since problem containers would be removed and/or breached and then added to the staged site.

3.2.2.4 Miscellaneous Waste. It is not known whether ISV can be applied directly to sites that contain miscellaneous waste such as contaminated heavy equipment. The process has been applied to sites with large timbers but not to sites that contain large, metal objects. Pretreatment and/or processing from the subsurface may allow for in situ treatment, but this would have to be demonstrated and a further study performed. Retrieval followed by ISV, with an intermediate sorting/sizing step, would be the quickest way to treat this type of waste stream.

3.3 Site Pre-conditioning Logic

Site Pre-Conditioning Logic for ISV Application to Buried Wastes



4. STATUS OF TECHNOLOGY FOR BURIED WASTE APPLICATIONS

In Section 3, the requirements and some of the on-going work is referenced that is required to make ISV technology applicable to OU 7-13/14. Much of this work is at different stages of development at the current time and some of this work is only now being formulated as the unique requirements for the treatment of OU 7-13/14 and other mixed waste sites within the DOE complex are critically characterized. Although ISV technology has some distinct limitations as a mixed waste treatment technology, it has three strengths that make it uniquely attractive as a potential technology of choice; (1) it limits excavation and the environmental/ personnel exposure that results from excavation, (2) it provides an excellent waste form that will not breakdown by weathering effects, and (3) it promises to be one of the most cost effective mixed waste treatment technologies available.

Note: See Section 4.7, which addresses the general cost effectiveness of ISV.

4.1 Soil Additions to Promote Vitrification [5,29,30,33]

This technology is reasonably well established and understood as characterized by the work completed on the DOE Savannah River Site ISV of Low-Alkali Soils. This technology will continue to develop on a site-specific basis as Geosafe employs soil testing and characterization to arrive at the desired vitrified product for each requirement where ISV is used.

4.2 Pressure Injection of Solids [5,29,30,33]

This is a common geotechnical engineering practice that is often used for the injection of grout and similar materials. High pressure injection of buried wastes has been demonstrated at DOE's INEL facility by a Westinghouse Hanford geotechnical engineering group. Additional work focused on building on the work to date has been proposed by Loomis and Farnsworth of the INEL as a needed pre-conditioning technology to address voids that exist in the INEL buried waste. Battelle/PNL employed this method for filling the crib void volume before performing the ISV demonstrations on the 116-B crib. The challenge exists to prove through demonstration that this technology will extend ISV's applicability, but it is believed to be achievable.

4.3 Dynamic Compaction [5,29,30,33]

This is also a common geotechnical engineering practice that is used for the compaction of soils. This technology has been demonstrated by Westinghouse Hanford. It is believed to be an alternative method to Dynamic Disruption to breach sealed containers, but to accomplish it using a non-intrusive method. This may offer other advantages by minimizing the potential for unplanned emissions associated with intrusive breaching. A significant development need for the use of dynamic compaction is for the development of a verification method that can determine if a sufficient change in the integrity of buried containers has occurred to allow for safe ISV processing.

4.4 Dynamic Disruption [5,29,30,33]

This is also a well-understood geotechnical engineering practice that is used for insertion of metal columns (vibrating beams or rods) or sheeting (plates) into the soil for various purposes. Its application to waste compaction has been demonstrated at DOE's Hanford site by Westinghouse Hanford. Bechtel Environmental performed this method of pre-conditioning at the GE/Spokane site, to disrupt (breach intrusively) 80 drums containing soil and water, prior to Geosafe's performance of the National TSCVA Demonstration project at the site. Additional technology development is required in this area to establish positive breaching for a wide range of sealed containers as part of an overall ISV pre-conditioning methodology.

Note: The planned/designed approach for dynamic disruption of drums which have thin walls has been demonstrated and proved to be effective, but the disruption/breaching of heavier walled vessels such as pressure cylinders requires a different approach such as staging which involves excavation and restaging followed by ISV in created treatment cells/pits. Excavation and Restaging or ISV with Retrieval, may also prove to be an overall cost effective technology as addressed in Sections 4.6 and 4.7.

4.5 Thermally-Assisted VOC Removal via SPSH [5,9,34]

This is a well-understood method for removal of VOC's and SVOC's from contaminated soil sites. Enhanced volatilization of organics is achieved by heating the soil while pulling a vacuum on the soil which extends the applicability of ambient vapor extraction processes. There are several different methods of heating the soil for this purpose. Geosafe prefers a technology developed by Battelle Pacific Northwest Laboratories called Six-Phase Soil Heating (SPSH) that is able to work in lower permeability soils than other vapor extraction (VEX) processes. It is also favored because it provides a more uniform heating pattern and is more controllable. During SPSH, electric current flows through the soil, heating it up and removing the soil moisture and volatile organic compounds. When this technology is employed in combination with ISV, it addresses in a positive fashion a serious operating concern that ISV has experienced. That is the issue of pressure build-up when high vitrification temperatures (1600 to 2000°C) are experienced in the presence of drum sized quantities of volatiles. The issue that is perhaps best addressed by six phase heating is the concern that the ISV process can potentially drive volatile components into the surrounding soil.

This technology approach was the one selected by the alternatives analysis for source remediation at trench T-3 for the Rocky Flats Environmental Technology Site, Operable Unit No. 2. This technology combination must still be considered developmental and its implementation in combination with ISV as an integrated technology should be demonstrated.

4.6 Excavation and Restaging [5, Append. A]

This technology employs standard earth-working technologies. Restaging involves controlling the location and concentration of wastes that are co-located within the treatment volume with the soil. Standard compaction methods may be employed to density the emplaced soil and wastes. Staging has been employed in several of Geosafe's commercial remediation projects. It is recognized that this option is often considered last due to associated cost and safety issues, particularly for radioactive sites. For these reasons, priority consideration should be given to making a site acceptable for processing by the other non-excavation related pre-conditioning options if possible. In addition, the option of preparing more robust equipment, and operating under secondary containment, may also be preferable to excavation and restaging.

4.7 General Cost Effectiveness of ISV

The general cost effectiveness of ISV is presented here based on four sources; actual cost data provided by Geosafe Corporation on projects executed to date, cost estimates and cost data provided by other sources, cost estimates provided by Geosafe for the usage of pre-conditioning technologies cited above and INEL studies comparing the SDA buried waste treatment cost by specific remediation technology in a systematic manner.

It must be recognized and understood that costs are highly site-specific and will vary with on-site conditions. Treatment is most economical when treating large sites to maximum depths. it must also be recognized that when the waste is treated in situ, cost adders to the initial cost estimates become much less significant, since measures to protect personnel and the environment from potential radioactive exposure are substantially reduced.

4.7.1 Actual Cost Data Supplied by Geosafe Corporation [33]

Actual cost data was supplied by Geosafe Corporation based upon three commercial projects. This data was supplied in the form of a graph supplied that shows the treatment costs as $/ton as a function of annual tonnage and is included in Appendix "D" as Figure 2 of Geosafe's letter of 1/19/96: "Geosafe Commercial ISV Treatment Costs." This cost data provides a breakout of the treatment cost with and without mobilization and demobilization costs which adds approximately $65/ton to the cost. The total treatment cost for ISV varies between $405/ton to $585/ton based upon these three commercial projects which were hazardous waste sites and includes all costs associated with treatment, permitting, regulatory compliance, site closure, Geosafe's overheads and profit. Geosafe states that, "The application of ISV to DOE sites is expected to have additional costs such as compliance with DOE orders, site specific training requirements and radiation monitoring which have not been included in our commercial costs."

4.7.2 <u>Economic Analysis Supplied by EPA</u> [Append. B]

An economic analysis was carried out by the Environmental Protection Agency (EPA) at the former site of Parsons Chemical Works, Inc.; a Superfund site located in Grand Lodge, Michigan under the Superfund Innovative Technology Evaluation (SITE) Program for the demonstration of

ISV on approximately 330 yd^3 of contaminated soil. Estimates for capital and operating costs were determined for a treatment volume of approximately 3,200 yd^3 (5700 tons) based on the site demonstration. The estimated cost for treatment when the soil was staged into nine 15-foot deep cells is \$780/yd^3 (\$430/ton). This cost represents a staged process approach for ISV where the contaminated soil is first excavated and then placed into treatment cells which have been created for the vitrification of the excavated waste. A copy of the EPA Superfund Innovative Technology Evaluation (SITE) Program Summary Report titled, "Geosafe Corporation In Situ Vitrification Technology" which provides a detailed description of this demonstration is included in Appendix "B." This SITE Report under Table 1: Criteria Evaluation for the Geosafe In Situ Vitrification Technology, cost criteria column, states; "This cost is based on data gathered from the Parsons site. Costs are highly site-specific and will vary with on-site conditions."

Note: The staged ISV process which was employed in this demonstration will have a higher cost than an ISV process without excavation and the creation of waste cells.

4.7.3 <u>Pre-conditioning Technology Cost Estimates Supplied by Geosafe Corporation</u> [33]

Geosafe Corporation provided the following cost estimates for ISV pretreatment techniques that are discussed in Sections 4.2, 4.3, and 4.3 above as techniques that may be employed, if required, to address treatment requirements for the usage of ISV for site-specific needs:

> <u>4.7.3.1 Pressure Injection of Solids; unit cost = \$100 to \$140/yd^3 of material treated.</u>
>
> <u>4.7.3.2 Dynamic Compaction; unit cost = \$1.50/ft^2 of treatment surface based upon 3 foot centers for the application.</u>
>
> <u>4.7.3.3 Dynamic Disruption; unit cost = \$2.00/ft^2 of treatment surface based upon 3 foot centers to a depth of 15 feet.</u>

4.7.4 <u>INEL Studies Comparing the SDA Buried Waste Treatment Cost by Technology</u> [26,27]

A System Design Study (SDS) was carried out at the INEL and a report titled, "Preliminary Systems Design Study Assessment Report"[26] issued in July 1991. This study was carried out to examine techniques available for the remediation of hazardous and transuranic (TRU) waste stored at the RWMC Subsurface Disposal Area (SDA). The evaluation process for this study consisted of establishing groupings of treatment technologies that in a systematic and

Table 6. Life-cycle segments for SDS system concepts.

System Concept	Number	DT&E ($ x 10^6)	Product Construction ($ x 10^6)	10 Years Operation ($ x 10^6)	Waste Transport ($ x 10^6)	Waste Disposal ($ x 10^6)	Facility D&D ($ x 10^6)	Total Life Cycle ($ x 10^6)
Melting/Incineration with LLW Presort	2-EG-1	293	777	1,030	12.9	940	54.0	3,107
ISV and Retrieval	2-EB-3	59	210	180	27.4	1,613	43.3	2,133
Melting/Incineration with LLW Postsort	2-EG-4	258	667	900	12.0	900	67.5	2,805
Thermal Treatment with LLW Presort	3-IT-1	299	1,043	1,310	18.5	1,196	67.3	3,934
Thermal/Solidification with LLW Postsort	3-IT-3	276	833	1,080	13.2	992	51.5	3,246
Chemical Oxidation/ Solidification	3-IT-8	330	705	1,050	15.0	1,093	31.9	3,225
Pyrolysis & Acid Leach Pu Extraction	3-EB-6	229	545	1,020	16.8	1,119	22.9	2,953
Molten Salt Oxidation	3-BE-7	268	691	1,750	21.2	1,321	50.0	4,101
Waste Solidification and Packaging	4-BE-2	249	597	1,590	16.4	1,103	30.3	3,586
Waste Volume Reduction & Packaging	4-BE-4	284	817	1,830	17.0	1,130	38.5	4,117

Table II-10-1. System concept cost summary (includes all costs for the appropriate subsystems)

System Concept	Number	DT&E ($ x 10^6)	Prod. Construction ($ x 10^6)	Annual Operating ($ x 10^6)	Total Life Cycle ($ x 10^6)	Life Cycle[a] ($/Cubic Yard)
Barrier	1-BE-1	76	162	0.1	239	538
In situ vitrification	1-EB-2	37	124	26	288	648
Melting/incineration with LLW presort	2-EG-1	293	777	103	2096[b]	4716[b]
ISV and retrieval processing	2-EB-3	59	210	36	447[b]	1005[b]
Melting/incineration with LLW postsort	2-EG-4	258	667	90	1821[b]	4097[b]
Thermal treatment/solidification with LLW presort	3-IT-1	299	1043	131	2651[b]	5965[b]
Thermal treatment/solidification with LLW postsort	3-IT-3	276	833	108	2190[b]	4928[b]
Pyrolysis/acid leach with plutonium extraction	3-EB-6	229	545	102	1796[b]	4041[b]
Molten salt oxidation	3-BE-7	268	691	175	2708[b]	6093[b]
Chemical oxidation/solidification	3-IT-8	330	705	105	2090[b]	4703[b]
Sort, treat, and repackage	4-BE-2	249	597	159	2432[b]	5472[b]
Volume reduction and repackage system	4-BE-4	284	817	183	2932[b]	6597[b]

a. Based on 444,444 cubic yards of untreated waste.

b. Excludes disposal cost of the excavated waste.

comprehensive fashion addressed the treatment requirements for the buried waste at the SDA. The results of the evaluation identified twelve selected system concepts from the twenty-seven systems critically reviewed for subsequent detailed evaluation and assessment. A Life Cycle Cost was then arrived at for each of the twelve selected systems that included the demonstration, evaluation and testing cost, the production construction cost, and the annual operational cost. See Table II-10-1, titled, "System Concept Cost Summary" for this study which is included here for easy reference.

The twelve selected systems included two in situ systems; ISV and the Barrier System, and ten ex situ systems. As can be seen in Table II-10-1, the Barrier System had the lowest Life Cycle Cost at $538/yd^3$, followed very closely by ISV at $648/yd^3$ and then followed by the remaining ex situ[3]. Life Cycle Costs that ranged from $1005/yd^3$ to $6597/yd^3$. The lowest Life Cycle Cost for an ex situ system concept is the combination of ISV and retrieval processing with a cost of $1005/yd^3$. The next lowest ex situ system concept is Pyrolysis/acid leach with plutonium extraction that has a Life Cycle Cost of $4041/yd^3$ which is more than $3000/yd^3$ greater than the ISV and retrieval system concept.

A subsequent INEL study was carried out to determine additional costs for the ten ex situ system concepts identified in the earlier report cited above. The additional costs which are identified in this report titled, "Low-Level and Transuranic Waste Transportation, Disposal, and Facility Decommissioning Cost Sensitivity Analysis"[27] dated May 1992, are low-level waste (LLW) and TRU waste <u>transportation, disposal, and facility decommissioning costs.</u>

Note: Since these costs are associated with the ex-situ system concepts only, since the in-situ system concepts are premised to require no further action; the life cycle cost disparity between in-situ and ex-situ systems becomes larger when these costs are added.

These costs for transportation, disposal, and facility decommissioning must be combined with the SDS life cycle costs identified above to reflect an improved life-cycle cost estimate. The updated cost estimate for the ten ex situ system concepts is included here for easy reference and titled, "Table 6 - Life-cycle segments for SDS system concepts."

As can be seen in Table 6, the lowest life cycle cost estimate for an ex situ system concept is ISV and Retrieval with a life-cycle cost of $\$2,133 \times 10^6$. This life cycle cost is substantially lower than the next system concept ex situ system, which is Melting/Incineration with LLW Presort with a life cycle cost of $\$2,805 \times 10^6$. In doing an overview of both reports, it is of interest to compare the life cycle cost of ISV without retrieval at $\$288 \times 10^6$ with all of the ex situ life cycle cost estimates. There is a factor of between 10 and about 23 between the ISV life cycle cost and all other ex situ life cycle costs represented by the systems design study.

If ISV can be achieved without retrieval it represents a potential cost savings of $\$1,845 \times 10^6$ when compared with ISV with retrieval and between $\$2,517 \times 10^6$ and $\$3,829 \times 10^6$ when compared with all the other ex situ system concepts identified by the SDS.

The only in situ system concept that was less expensive than ISV was the Barrier System. The Barrier System concept represents no actual treatment of the waste but rather the employment of an isolation barrier between the waste and all environmental interfaces. The use of ISV, by contrast, represents a thermal treatment by vitrification rendering the waste into a chemically inert and stable final waste form. a comparative analysis of the difference in cost between ISV with a life cycle cost of \$288 x 10^6 and the Barrier System with a life cycle cost of \$239 x 10^6 yields a cost savings of only \$49 x 10^6 by using the Barrier System.

4.7.5 Cost Comparison Between Sources

In comparing the cost of ISV from the sources above; Geosafe Commercial Experience cost data, the EPA SITE summary report, the INEL Preliminary Systems Design Study Report, and the sequel INEL report; Low-Level and Transuranic Waste Transportation, Disposal, and Facility Decommissioning Cost Sensitivity Analysis, it is a significant finding that there is overall good agreement between the estimated costs from the INEL reports, the estimated costs from the EPA report, and the actual costs reported by Geosafe on three commercial projects performed in the field.

The Geosafe commercial ISV reported treatment costs vary between \$400 to \$600 per ton treated, whereas the EPA SITE report estimates cost for the ISV staging project at the Parsons Site to be \$430 per ton treated or about \$780/yd^3 and the Systems Design Study estimates the cost to be \$648/yd^3 which is equivalent to about \$630 per ton treated. If retrieval is required with ISV then the cost increases by a factor of about 7.4 from \$648/yd^3 to \$4795/yd^3.

Correspondingly, if ISV can be employed with the pre-conditioning steps and the cost estimates provided by Geosafe and without retrieval, the treatment costs will increase by about 18.3% from \$648/yd^3 to \$793/yd^3. It is obvious from this comparison that ISV with pre-conditioning is much more cost effective than ISV with retrieval. (see Appendix F, Miscellaneous Calculations).

5. REFERENCES

1. C. M. Barnes, K. Garcia, J. Prendergast, *Preliminary Development of Alternative Remediation Technologies and Identification of Data Needs for 0 U 7-13114 Feasibility Study,* LMIT Engineering Design File, EDF ER-WAG7-78, September 6, 1995.

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APPENDIX A

Maralinga Site Memorandum from Geosafe

Geosafe Corporation

2950 George Washington Way
Richland, WA 99352
(509) 375-0710
FAX: (509) 375-7721

SENT BY COURIER

November 29, 1995

Mr. Jack Prendergast
L.M.I.T.
IRC Building, Rm 128
2351 North Boulevard
Idaho Falls, ID 83415-2203

Dear Mr. Prendergast:

MIXED TRU-CONTAMINATED BURIED WASTE APPLICATION OF IN SITU VITRIFICATION (ISV) TO THE MARALINGA SITE IN AUSTRALIA

It was nice to talk with you last week concerning the ISV application in Australia. As you requested, I am transmitting a summary paper to you concerning the recent radioactive demonstrations conducted by Geosafe at the Maralinga site. In addition, I'm enclosing the November, 1995 edition of Geosafe Corporation's In Situ Vitrification Technology Update newsletter. The newsletter includes an article on the two radioactive demonstrations as well as an update on Geosafe's other commercial ISV projects.

I believe you will find that the enclosed information provides good evidence that the ISV technology can be used to remediate buried waste sites. The results from the two radioactive demonstrations are certainly encouraging for the difficult Maralinga conditions. Preliminary results and observations indicate the following:

- The ISV process effectively treated the soil and debris combinations in the pits including the 37 wt% steel and other debris (barytes bricks, cable, lead, bitumen stabilized soil, and plastic).

- The voids and gas generating materials in the pits (carbonates, sulfates, and organics) did not pose any processing difficulties with respect to off-gas treatment or containment. The data indicates that a full-scale ISV process machine designed specifically for this application will be capable of handling the higher off-gas temperatures and transient off-gas flows associated with the treatment of the buried wastes.

- Based on isokinetic off-gas sampling, the amount of uranium retained in the first demonstration melt exceeded 99.99%. Analyses for plutonium have not been completed but similar results are expected based on other testing.

- Following the demonstrations, health physics-related surveys of the equipment established that the insides of the off-gas containment hood, off-gas piping, and primary HEPA filters were free of detectable contamination above background levels. Consequently, decontamination of the equipment was not required.

- Based on preliminary gamma spectrometry analyses, convective currents in the melt resulted in the uniform distribution of the plutonium and uranium oxides within the vitreous phase in both melts.

Last week, we talked briefly about how the ISV technology could be implemented at Operable Unit (OU) 7 at the INEL to treat the buried wastes. Geosafe has significant full-scale commercial ISV experience in treating sites containing large amounts of buried debris including sealed containers and combustibles. In order to use the ISV technology on a site like OU 7, there are several different options to implement the ISV technology. These options are described in a Geosafe Corporation paper entitled Application of In Situ Vitrification to Buried Wastes, April 1995. Because the options described in that paper are directly relevant to the OU 7 site, I am enclosing a copy for your review. Specifically, there are two primary options for a site like OU 7.

The first primary option involves preconditioning techniques to make the site acceptable for ISV processing. Such preconditioning techniques may involve dynamic compaction or dynamic disruption to breach any sealed containers such as drums and to collapse voids. Dynamic disruption has been used by Geosafe to precondition a PCB-contaminated site that contained 80 sealed drums. The dynamic disruption method was found to be highly reliable and cost effective. Following dynamic disruption or dynamic compaction, and if deemed necessary, the use of a thermally assisted vapor extraction process could be employed to remove any excess volatile liquids, such as solvents, that may have been contained in the sealed containers prior to disruption. Note that a thermally assisted vapor extraction process would only be necessary if there were substantial volumes of pooled liquids. An additional preconditioning option that may be useful would be to pressure inject a slurry of glass formers to fill voids and to moderate the melt rate. This type of pressure injection technique has been used successfully to support prior ISV applications. Following these types of preconditioning steps, the ISV process could be directly applied to the site.

The second primary preconditioning option involves excavation and restaging for direct treatment by the ISV process. Any items found during the excavation and restaging process that are unacceptable for direct treatment, such as sealed drums or compressed gas cylinders, could be removed, or made suitable for treatment by first breaching the container. Pockets of concentrated materials could be distributed within the treatment volume. Geosafe believes that the vast majority of items disposed of in OU 7 would be acceptable for treatment with only minor alteration. Once the materials are restaged into an acceptable treatment configuration, the ISV process could be applied directly without other preconditioning methods. Although this method requires intrusive excavation and restaging, Geosafe is confident that this restaging option would be one of the lowest cost options while providing the highest degree of safety and treatment effectiveness.

Geosafe is confident in our ability to treat buried waste sites because of our commercial experience in treating sites that contain significant amounts of buried debris. We also have commercial experience in treating all contaminant classes (VOCs, SVOCs, metals, and radionuclides including plutonium). We have successfully implemented the ISV process on a commercial basis and have developed a wealth of experience over the last few years. The results from all three of our Superfund remediation projects have been extremely favorable.

It is important to note that the ISV process has come a long way since the ISV test program at INEL in the early 1990's. Many of the technical issues identified by INEL and PNL at that time have been resolved. At that time, the approach being investigated by INEL and PNL was to treat buried wastes directly with ISV without preconditioning. Direct treatment is a complex and difficult task. Preconditioning significantly reduces the complexity of the application and eliminates the difficulties that were identified by INEL and PNL in the early 1990's.

Jack, I hope this information meets your needs and expectations. If you have any questions concerning the Maralinga project, don't hesitate to contact me. Alternatively, you can contact either James Hansen or Matt Haass, regarding any aspect of ISV.

Sincerely,

LE Thompson

Leo E. Thompson
Maralinga Rehabilitation Program
ISV Project Manager

In Situ Vitrification of Mixed TRU-Contaminated Buried Wastes: Preliminary Results From Two Recent Radioactive Demonstrations

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PROJECT BACKGROUND

As part of the Maralinga Rehabilitation Program, the Australian Commonwealth Department of Primary Industries and Energy is evaluating the In Situ Vitrification (ISV) process for application to debris pits located at Maralinga's Taranaki Area. The ISV process has been selected as the preferred remedy for the debris pits (1).

The Maralinga site is a former nuclear weapons test range, located in the State of South Australia, that was used by the British in the 1950's and early 1960's for above ground testing (1). Seven atomic explosions (major trials) during 1956 and 1957 resulted in fission product fallout. Several hundred ancillary experiments (minor trials) were carried out, some of which resulted in the explosive dispersal of plutonium, uranium and beryllium in the open environment. Conventional chemical explosives were used in these tests. Plutonium was dispersed as fine oxide dusts, as sub-millimeter particles, and as surface contamination on large fragments of debris.

The Taranaki area is the site's most contaminated area. Twelve minor trials conducted at Taranaki involved the explosive dispersal of 22-kg of plutonium resulting in large amounts of contaminated debris and soil. The Taranaki site contains 21 burial pits that are believed to contain approximately 5 kg of plutonium, about 20-kg of enriched and depleted uranium, and various heavy metals including lead, barium, and beryllium, along with large amounts of debris. The debris includes massive steel plates and beams along with organic-based materials.

The ISV process was initially identified by the Commonwealth as the preferred alternative for stabilizing the Taranaki pits in the report by the Maralinga Technical Assessment Group (1). ISV was determined to be the leading candidate for this application because of the ability of the process to immobilize radionuclides in the vitrified product, the ability of the process to accommodate debris, the associated volume reduction, the ability of the process to destroy organic contaminants, and the improved occupational, public, and environmental safety benefits resulting from the in situ treatment.

To support the evaluation of the ISV technology for the application, Geosafe Corporation conducted a series of ten engineering-scale tests (up to 300-kg) and three intermediate-scale demonstrations (up to 4,500-kg) of the ISV process at the Maralinga site during 1995. The first intermediate-scale demonstration involved the use of cerium oxide as a surrogate for plutonium oxide. The chemical and physical properties of cerium in an ISV melt environment make it a good choice as a surrogate for plutonium (2). The second and third demonstrations used radioactive materials including blast debris from the original weapons tests. This paper provides an overview of the two radioactive demonstrations.

RADIOACTIVE ISV DEMONSTRATIONS

The principal goal for the intermediate-scale radioactive ISV demonstrations was to collect sufficient data to determine if the ISV process could be expected to effectively treat the contaminated soil and debris in the Taranaki pits. Specific objectives were established for each demonstration so that the performance of the ISV process and the resulting vitrified product could be evaluated against the performance criteria established for the project. Specific questions to be answered from the demonstrations included:

- Could the ISV process accommodate the debris combinations in the pits including the 37 wt% steel?
- Would the ISV melts grow large enough to fully encompass the debris and soil in the pits?
- Would plutonium be retained in the melt to a high degree (i.e., >99.99%)
- Would plutonium partition to any other phase such as the metallic phase at the base of the melt?
- Would the physical characteristics of the vitrified product meet the performance criteria established for the project.

Science and engineering advisors representing the Commonwealth helped determine ISV process performance criteria for the application, and were present to observe activities during key stages of the demonstration project.

The demonstrations were configured in a manner that was thought to best represent the configuration of the actual pits as well as the actual types and amounts of debris buried in the pits. Standard scaling relationships established for the ISV process were used in conjunction with historical data that describes the pits and the pit contents to develop scale mock-ups of a typical Taranaki pit.

An intermediate-scale (85-kW) system capable of producing melts up to 4,500-kg (5 tons) was constructed for the project. Figure 1 is a photograph of the ISV equipment as positioned for the first radioactive demonstration. This size of system provides cost effective data that can be directly scaled to the full-size application. 12.7-cm (5-in) diameter graphite electrodes were used for the two demonstrations. The off-gas treatment system was designed specifically for the radioactive buried waste application and is capable of handling the higher off-gas generation rates and higher off-gas temperatures that can result when processing buried wastes compared with melting only contaminated soil. In addition to the steel and radioactive materials, the pits included significant amounts of gas generating materials such as sulfates, carbonates, and organics.

The first radioactive demonstration involved the treatment of soil, 37 wt% steel debris, and other debris from the original weapons tests including bitumen-stabilized soil, plastic, electrical cable and barytes bricks, which are a barium sulfate-based radiation shielding material. Figure 2 is a photograph of the pit being filled with debris and soil. One kilogram of uranium oxide was buried in the trench to serve as a surrogate for plutonium. The uranium oxide was contained in a plastic bag and located in the center of the pit to serve as a highly localized area of contamination.

The second radioactive demonstration, which contained plutonium, was similar to the first demonstration and also included 37 wt% steel debris. Other debris included in the pit consisted of barytes bricks, lead, electrical cable, plastic, and bitumen-stabilized soil. To provide a source of plutonium, a steel plate originating from the weapons tests was used that was contaminated with approximately 1.4 grams of plutonium oxide. Like the first radioactive demonstration, another one kilogram of uranium oxide was positioned in a plastic bag in the center of the pit.

Each demonstration melt was conducted at opposite ends of a trench. In order to best represent the geochemistry of the limestone-based soil surrounding the Taranaki pits, the tests were conducted in the Taranaki area adjacent to two of the larger waste burial pits.

The two demonstrations were conducted in September and October of 1995. The first demonstration occurred over an approximate 84 hour time period while the second demonstration occurred over an approximate 96 hour time period. During the operations, process-related data such as electrical power and off-gas related data was collected to support the design process for a full-scale ISV machine that will be tailored specifically for the site.

Following the two demonstrations, the resulting vitrified monoliths were excavated for examination, weighing, and sampling. The first demonstration monolith was determined to be 3,766-kg (4.15 tons). The second demonstration monolith was determined to be 4,292-kg (4.73 tons). Figure 3 is a photograph of the second demonstration monolith being weighed.

RESULTS

Both demonstrations were completed successfully. Physical characterization of the vitrified blocks and preliminary radiochemical analyses have been completed. Additional analyses, including a variety of leach tests, are currently underway. Based on the available data, the following observations and conclusions can be made concerning the demonstrations:

- The ISV process was demonstrated to be capable of melting the soil and debris combinations in the pit including the 37 wt% steel. In addition, the non-steel debris in the pit (barytes bricks, cable, lead, bitumen stabilized soil, and plastic) did not pose any processing difficulties.

- The voids and gas generating materials in the pits (carbonates, sulfates, and organics) did not pose any processing difficulties with respect to off-gas containment. The off-gas treatment system's high off-gas flow rate was fully sufficient to accommodate the high steady state off-gas generation rates and transient off-gas surges that resulted from the processing of the gas generating materials and voids.

- The target melt depth and width was exceeded, resulting in the complete treatment of the pit contents.

- The volume reduction for the soil and debris treated was 47% for the first demonstration melt and 55% for the second demonstration melt.

- The vitrified product had an average density of 2.7-g/cm^3. Chemical analyses of the vitrified products established that the composition was uniform.

- Based on isokinetic off-gas sampling, the amount of uranium retained in the first demonstration melt exceeded 99.99%. Analyses for plutonium have not been completed. However, a melt retention value exceeding 99.99% is expected for plutonium based on prior test data (3) and even greater retention levels are typical at full-scale.

- Following the demonstrations, health physics-related surveys of the equipment established that the insides of the off-gas containment hood, off-gas piping, and primary HEPA filters were free of detectable contamination above background levels (less than 0.25 Bq alpha and beta combined per 100 cm^2 surface area). Consequently, decontamination of the equipment was not required.

- The plutonium in the vitreous phase is not smearable. Significant intrusive sampling activities resulted in the creation and handling of many small fragments of vitrified product, including dusts, but did not result in the transfer of any detectable contamination to tools or personnel.

- Based on preliminary gamma spectrometry analyses, convective currents in the melt resulted in uniform distribution of the plutonium and uranium oxides within the vitreous phase in both melts. This result is consistent with many past ISV tests and demonstrations including previous demonstrations involving radioactive materials (3).

- The metal phase at the base of each melt was determined to be free of plutonium and uranium based on qualitative analyses. Quantitative analyses of the metal phase have not yet been completed. (Quantitative analyses of the metal phase from the non-radioactive cerium demonstration established that cerium did not partition to the metal phase.)

CONCLUSIONS

The data and observations resulting from all of the ISV tests and demonstrations conducted at the Maralinga site support the following primary conclusions concerning the likely performance of the ISV process on the Taranaki pits:

- The ISV process, at full-scale, can be expected to effectively treat the soil and debris combinations in the Taranaki pits.

- The data indicates that an ISV process machine designed specifically for this application will be capable of handling the higher off-gas temperatures and transient off-gas flows associated with the treatment of the buried wastes.

- The vast majority of the plutonium will be retained in the melt (>99.99%).

- The vitrified product will be a uniform, dense, hard product of high strength. (Many prior studies have established the outstanding durability and leach resistance of the ISV product.)

- The plutonium oxide will be effectively distributed throughout the main vitreous phase due to the convective currents that exist in ISV melts.

- Plutonium will not be distributed to any significant extent to other phases in the melt (i.e., metal phase, porous cold cap, surface insulation).

- The ISV process can be safely applied to the materials present at the Taranaki site.

The two radioactive demonstrations provided an opportunity to obtain site specific process performance data to evaluate the ISV process for this application. The data will be used to develop a remedial design plan for the full-scale application to determine the most efficient, safe and economical approach to treat the Taranaki pits with the ISV technology. In addition, the process data is being used to design a full-scale ISV process machine that is being tailored to accommodate the specific characteristics and treatment requirements of the site. The construction of the full-scale ISV machine is expected to commence in 1996 and the treatment of the Taranaki pits is expected to commence in 1997.

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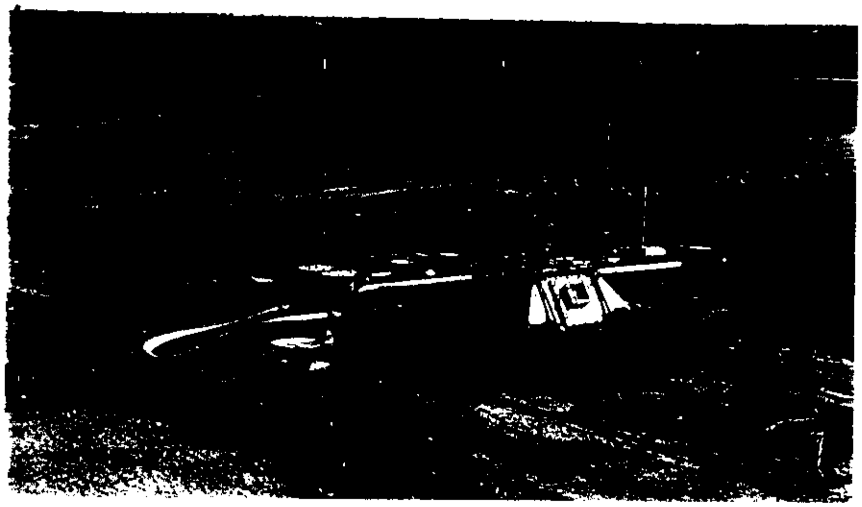
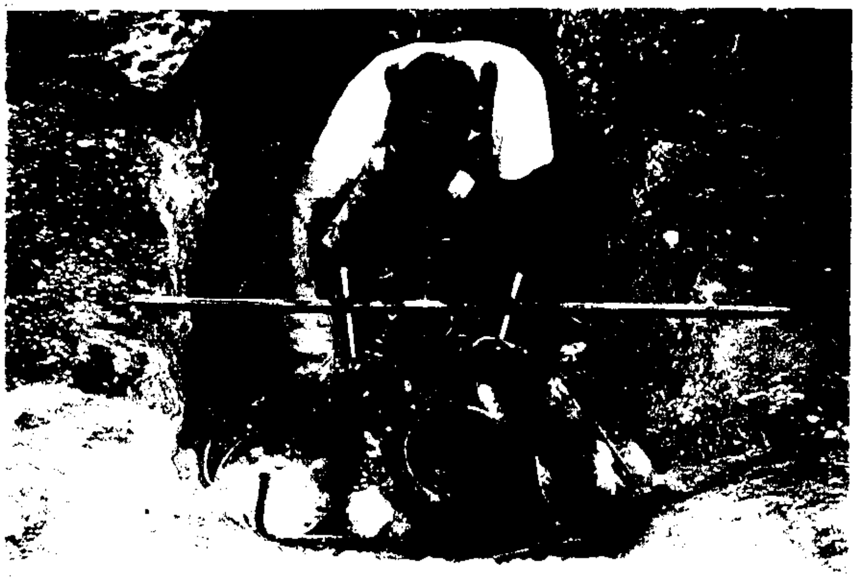


Figure 1 (top) shows the intermediate-scale ISV equipment at Taranaki during the first radioactive demonstration. Figure 2 (bottom left) shows one of the pits being filled with debris. Figure 3 (bottom right) shows the second demonstration monolith containing plutonium being weighed.



APPENDIX B

EPA SITE Summary on ISV

United States Environmental Protection Agency
Office of Research and Development Cincinnati, OH 45268
EPA 540/R-94/520a November 1994

EPA

SITE Technology Capsule

Geosafe Corporation In Situ Vitrification Technology

Abstract

The Geosafe In Situ Vitrification (ISV) Technology is designed to treat soils, sludges, sediments, and mine tailings contaminated with organic, inorganic, and radioactive compounds. The organic compounds are pyrolyzed and reduced to simple gases which are collected under a treatment hood and processed prior to their emission to the atmosphere. Inorganic and radioactive contaminants are incorporated into the molten soil which solidifies to a vitrified mass similar to volcanic obsidian.

This mobile technology was evaluated under the SITE Program on approximately 330 yd³ of contaminated soil at the Parsons site. Demonstration results indicate that the cleanup levels specified by EPA Region V were met and that the vitrified soil did not exhibit leachability characteristics in excess of regulatory guidelines. Process emissions were also within regulatory limits.

The Geosafe ISV Technology was evaluated based on seven criteria used for decision-making in the Superfund Feasibility Study (FS) process. Results of the evaluation are summarized in Table 1.

Introduction

This Capsule provides information on the Geosafe ISV Technology, a process designed to treat contaminated media by using an electrical current to heat and vitrify the subject material. The Geosafe ISV Technology was investigated under the Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program during March and April 1994 at the former site of Parsons Chemical Works, Inc. (Parsons). The Parsons site is a Superfund site located in Grand Ledge, MI and currently undergoing a removal action under the supervision of the EPA Region V. Soils at the Parsons site were previously contaminated by normal facility operations including the mixing, manufacturing, and packaging of agricultural chemicals. The technology was evaluated on these soils which were contaminated with pesticides (primarily chlordane, dieldrin, and 4,4'-DDT),metals (especially mercury), and low levels of dioxins/furans. A total of approximately 3,000 yd³ of contaminated soil was treated in nine pre-staged treatment settings. The Demonstration Test evaluated the system performance on one of these settings.

Information in this Capsule emphasizes specific site characteristics and results of the SITE Demonstration at the Parsons site. This Capsule presents the following information:

- Technology Description
- Technology Applicability
- Technology Limitations
- Site Requirements
- Process Residuals
- Performance Data
- Economic Analysis
- Technology Status
- SITE Program Description
- Sources of Further Information

Technology Description

The ISV Technology demonstrated by Geosafe Corporation (Richland, WA) operates by means of four graphite electrodes, arranged in a square and inserted a short distance into the soil to be treated. A schematic of the Geosafe process is presented in Figure 1.

ISV uses electrical current to heat (melt) and vitrify the treatment material in place. A pattern of electrically conductive graphite containing glass frit is placed on the soil in paths between the electrodes. When power is fed to the electrodes, the graphite and glass frit con-

Table 1. Criteria Evaluation for the Geosafe In Situ Vitrification Technology

Criteria						
Overall Protection of Human Health and the Environment	*Compliance with ARARs*	*Long-Term Effectiveness*	*Short-Term Effectiveness*	*Reduction of Toxicity, Mobility, or Volume through Treatment*	*Implementability*	*Cost*
Provides both short- and long-term protection by destroying organic contaminants and immobilizing inorganic material. *Remediation can be performed in situ, thereby reducing the need for excavation.* *Requires off-gas treatment system to control airborne emissions. System can be specifically designed to handle emissions generated by the contaminants in the media being treated.* *Technology can simultaneously treat a mixture of waste types (e.g., organic and inorganic wastes).*	*Requires compliance with RCRA treatment, storage, and land disposal regulations (for a hazardous waste). Successfully treated solid waste may be delisted or handled as nonhazardous waste.* *Operation of on-site treat ment unit may require compliance with location-specific ARARs.* *Emission controls may be needed to ensure compliance with air quality standards depending upon local ARARs and test soil components.* *Scrubber water will likely require secondary treatment before discharge to POTW or surface bodies. Disposal requires compliance with Clean Water Act regulations.*	*Effectively destroys organic contamination and immobilizes inorganic material.* *Reduces the likelihood of contaminants leaching from treated soil. ISV glass is thought to have a stability similar to volcanic obsidian. The vitrified product is conservatively estimated to remain physically and chemically stable for approximately 1,000,000 years.* *May allow re-use of property after remediation.*	*Effectively destroys organic contamination and immobilizes inorganic material.* *Vitrification of a single 15-ft deep treatment setting may be accomplished in approximately ten days. Treatment times will vary with actual treatment depth and site-specific conditions.* *Presents potential short-term exposure risks to workers operating process equipment. Temperature and electric hazards exist.* *Some short-term risks associated with air emissions are dependent upon test material composition and off-gas treatment system design.* *Staging, if required, involves excavation and construction of treatment areas. A potential for fugitive emissions and exposure exists during excavation and construction.*	*Significantly reduces toxicity and mobility of soil contaminants through treatment.* *Volume reductions of 20 to 50% are typical after treatment.* *Some inorganic contaminants, especially volatile metals, may escape the vitrification process and require subsequent treatment by the off-gass treatment system.* *Some treatment residues (e.g., filters, personal protective equipment) may themselves be treated during subsequent vitrification settings. Residues from the final setting, including expended or contaminated processing equipment may require special disposal requirements.* *Volume of scrubber water generated is highly dependent upon soil moisture content, ambient air humidity, and soil particulate levels in the off-gas.*	*A suitable source of electric power is required to utilize this technology.* *Equipment is transportable and can be brought to a site using conventional shipping methods. Weight restrictions on tractors/trailers may vary from state to state.* *Necessary support equipment includes earth-moving equipment for staging treatment areas (if required) and covering treated areas with clean soil. A crane is required for off-gas hood placement and movement.* *The staging of treatment areas is recommended for areas where the contamination is limited to shallow depths (less than eight feet).* *The soil oxide composition must provide sufficient electrical conductivity in the molten state and adequate quantites of glass formers to produce a vitrified product. Oxides can be added to soil to corrected for deficiencies.* *Groundwater should be diverted away from treatment area to improve economic viability.*	*The estimated cost for treatment when the soil is staged into nine 15-ft deep cells is approximately \$780/yd³ (\$430/ton). This cost is based on data gathered from the Parsons site. Costs are highly site-specific and will vary with on-site conditions.* *Treatment is most economical when treating large sites to maximum depths.* *Electric power is a major element of costs associated with ISV processing. Other important factors (in order of significance) include labor costs; startup and fixed costs; equipment costs; and facility modifications and maintenance costs.* *Moisture content of the media being treated directly influences the cost of treatment since electric energy must be used to vaporize water before soil melting occurs.* *Sites that require staging and extensive site preparation will have higher overall costs.*

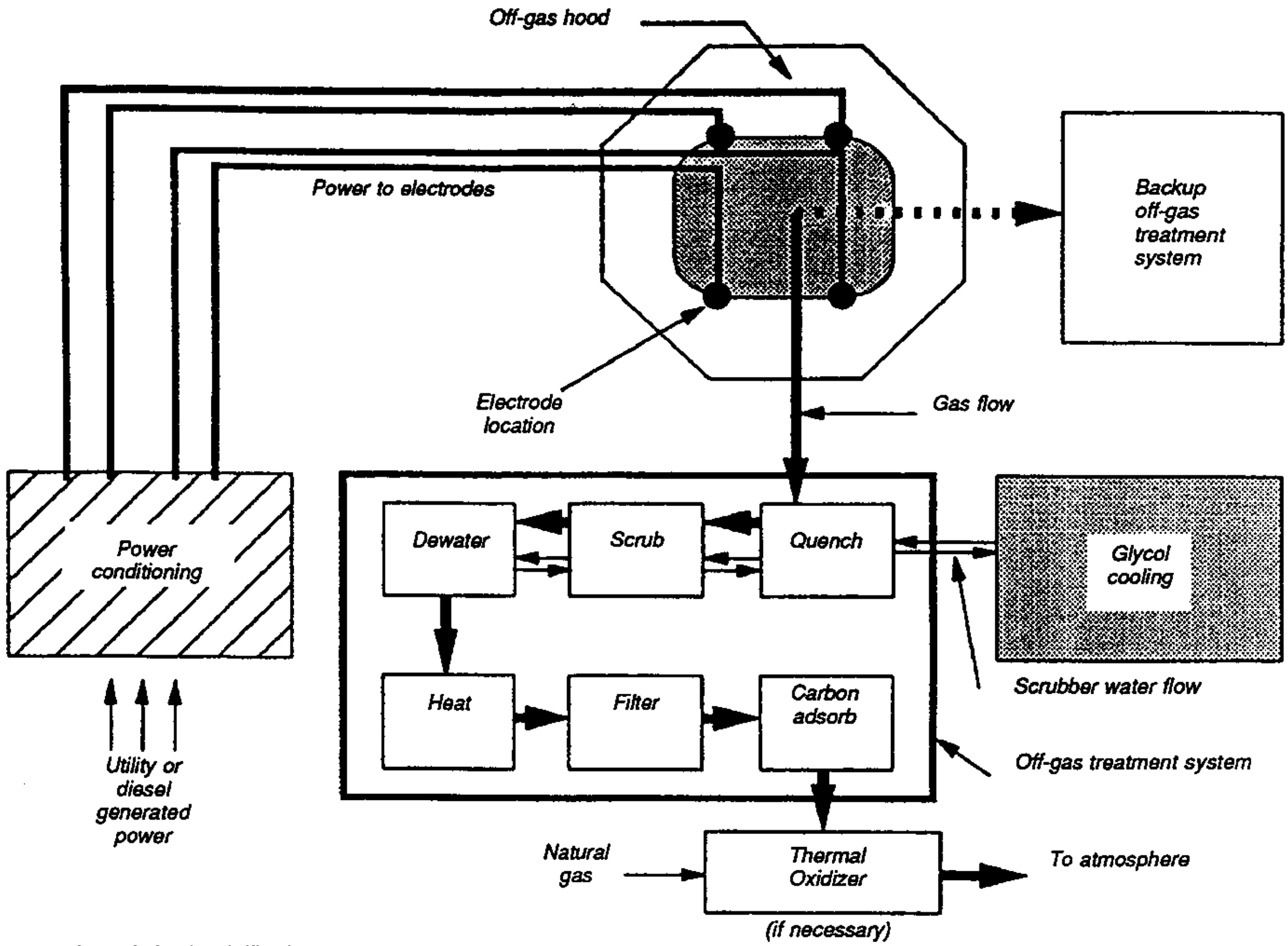


Figure 1. *Geosafe in situ vitrification process.*

ducts the current through the soil, heating the surrounding area and melting directly adjacent soil.

Molten soils are electrically conductive and can continue to carry the current which heats and melts soil downward and outward. The electrodes are allowed to progress down into the soil as it becomes molten, continuing the melting process to the desired treatment depth. One setting of four electrodes is referred to as a "melt." Performance of each melt occurs at an average rate of approximately three to four tons/hr.

When all of the soil within a treatment setting becomes molten, the power to the electrodes is discontinued and the molten mass begins to cool. The electrodes are cut near the surface and allowed to settle into the molten soil to become part of the melt. Inorganic contaminants in the soil are generally incorporated into the molten soil which solidifies into a monolithic vitrified mass similar in characteristics to volcanic obsidian. The vitrified soil is dense and hard, and significantly reduces the possibility of leaching from the mass over the long term.

The organic contaminants in the soil undergoing treatment are pyrolyzed (heated to decomposition temperature without oxygen) and are generally reduced to simple gases. The gases move to the surface through the dry zone immediately adjacent to the melt, and through the melt itself. Gases at the surface are collected under a stainless steel hood placed over the treatment area and then treated in an off-gas treatment system. The off-gas treatment system comprises a quencher, a scrubber, a demister, high efficiency particulate air (HEPA) filters, and activated carbon adsorption to process the offgas before releasing the cleaned gas through a stack. A thermal oxidizer can be used following the off-gas treatment system to polish the offgas before release to the atmosphere. A thermal oxidizer was utilized during the SITE Demonstration at the Parsons site.

Technology Applicability

The Geosafe ISV Technology is a stand-alone process that can be used to treat a wide variety of media including soils, sludges, sediments, and mine tailings. It is a mobile system with process equipment permanently mounted on three trailers. The hood and remaining equipment are transported on two additional trailers.

The soil type treated during the Demonstration was a clay-like soil with some sand and gravel present. Contaminants suitable for remediation by this technology may be organic or inorganic. The technology has also been successfully demonstrated on radioactive and mixed (hazardous and radioactive) wastes by Battelle Memorial Institute for the U.S. Department of Energy, but supporting data for this claim was not gathered as part of the Demonstration Test. Testing to date does not indicate an upper limit of contamination restricting successful remediation if the composition of the material is suitable for treatment (see Technology Limitations). The technology is also being developed for buried waste, underground tank, and barrier wall applications.

The technology can remediate contaminated materials in situ. Alternatively, contaminated materials may be excavated, consolidated, and staged in prepared treatment settings when the contamination zones are shallow (less than eight ft) or scattered. Other processing configurations are under development for unique applications.

Technology Limitations

The technology has the capability of treating large areas in multiple treatment settings. The size of each treatment setting is dependent on the electrode spacing appropriate for remediation. At the Parsons site, each treatment setting covered a 27-ft by 27-ft ground surface area. Adjacent settings can be melted until the entire contaminated area is treated. Melt settings are configured such that each area melts and fuses into the previous setting, leaving one large vitrified block after treatment. This overlap ensures treatment of the material between settings.

The maximum acceptable treatment depth with the current equipment is 20 ft below land surface (BLS); however, full-scale tests at Geosafe's testing facilities in Richland, WA have demonstrated that the technology can successfully reach a depth of approximately 22 ft BLS. Treatment at the Parsons site typically reached depths of 15 to 19 ft BLS.

The presence of large amounts of water in the treatment media may hinder the rate of successful application of the Geosafe technology since electrical energy is initially used to vaporize this water instead of melting the contaminated soil. The resulting water vapors must also be handled by the off-gas treatment system. Treatment times are thus prolonged and costs increased when excess water is present.

The overall oxide composition of the test soil determines properties such as fusion and melting temperatures, and melt viscosity. Soil to be treated must contain sufficient quantities of conductive cations (K, Li, and Na) to carry the current within the molten mass. Additionally, the soil should contain acceptable amounts of glass formers (Al and Si). Most soils worldwide have an acceptable composition for ISV treatment without composition modification. Geosafe determines the oxides present in the soil prior to treatment. A computer-based model is then used to determine the applicability of the site for vitrification. The model can also identify oxide composition levels that require modification before treatment.

The type of contamination present on-site affects the off-gas treatment system more dramatically than it affects the rest of the ISV system. For this reason, the off-gas treatment system is modular in configuration, allowing treatment of the off-gases to be site-specific. The extent of modularity is expected to increase with future units.

Heat removal limitations of the current equipment dictate that the organic content of the treatment media be less than 7 to 10% by weight. To minimize pooling of treated metals at the bottom of a melt, which may result in electrical short-circuiting, metals content must be less than 15% by weight. The volume of inorganic debris is limited to 20% or less.

Previous experience has indicated that safe, effective treatment cannot be assured when pockets of vapor or buried drums exist beneath the soil surface. The gases released may cause bubbling and splattering of molten material, resulting in a potential safety hazard. For this reason, extensive site characterization is recommended prior to treatment if buried drums are suspected. Combustible materials generally do not present processing difficulties since they decompose relatively slowly as the melt front approaches. Full-scale demonstrations have been successfully conducted on sites containing significant quantities of combustibles such as wooden timbers, automobile tires, personal protective equipment, and plastic sheeting.

Site Requirements

The site requirements for the Geosafe ISV technology are a function of the size of the equipment used. The site requirements are also determined, in part, by whether the soil is excavated and staged prior to treatment. Adequate area is required to accommodate staging, if employed, and to support the off-gas treatment system and the power conditioning system which feeds the electrodes. Space for maneuvering a crane is also necessary to allow placement and removal of the off-gas containment hood and to assist in the placement of the electrodes.

At the Parsons site, the original soil contamination was relatively shallow, five ft or less, and located in three main areas. To increase the economic viability of treatment at this site, the contaminated soil was excavated and consolidated into a series of nine treatment cells. The cell walls were built using concrete, cobble, and particle board as shown in Figures 2 and 3. The cells were constructed by trenching an area of the site, installing particle board and concrete forms, and pouring concrete into the forms to create the nine cell settings. A one-ft layer of cobble was placed in the bottom of each cell, and approximately two ft of cobble was used to surround the exterior of the cell forms. The use of cobble at the sides was intended as a means to retard melting out into adjacent clean soil. The bottom cobble was used to provide a drainage pathway for water that was known to be present on-site; the resultant flow of water was directed to a drainage trench. After construction, the cells were filled with contaminated soil from the site, and topped with a layer of clean soil.

During the treatment of the first few cells, problems with the cell design were observed. The intense heat that was melting the soil was also thermally decomposing the particle board forms. Analysis of water samples collected from the diversion system surrounding the cells identified volatiles (benzene), phenolics, and epoxies that were

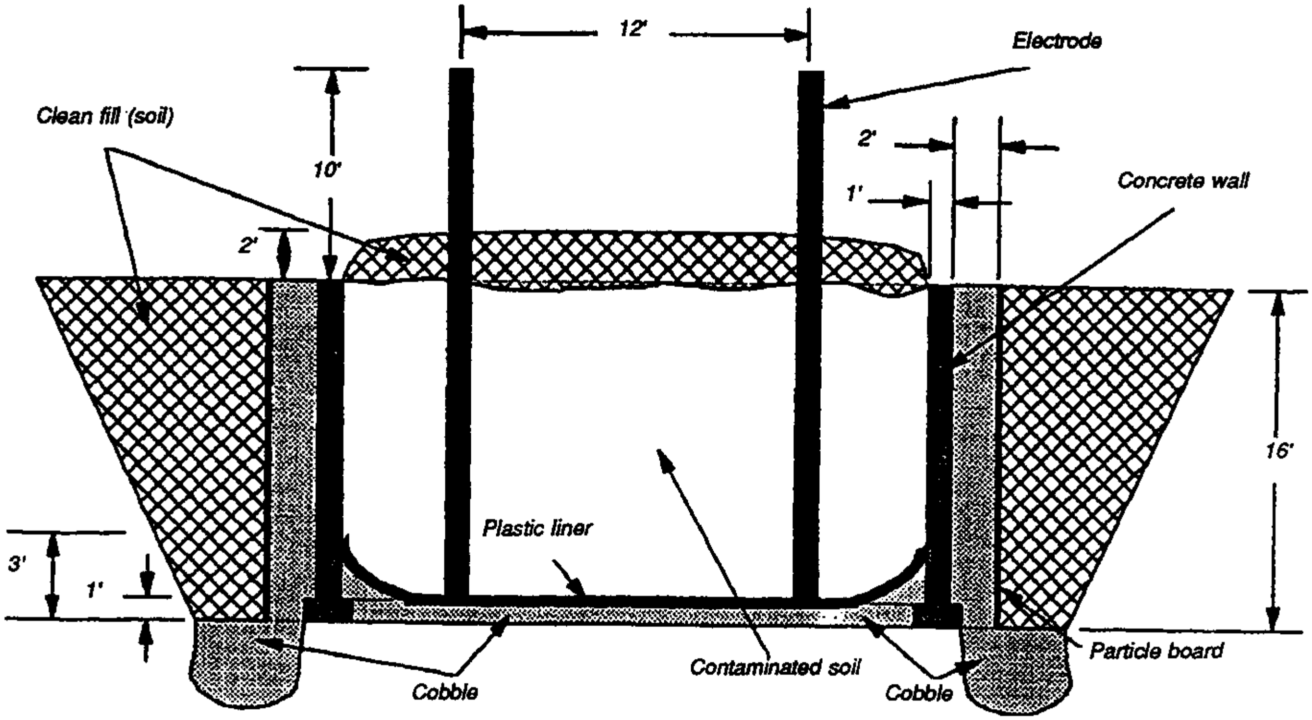


Figure 2. Side view of typical treatment cell.

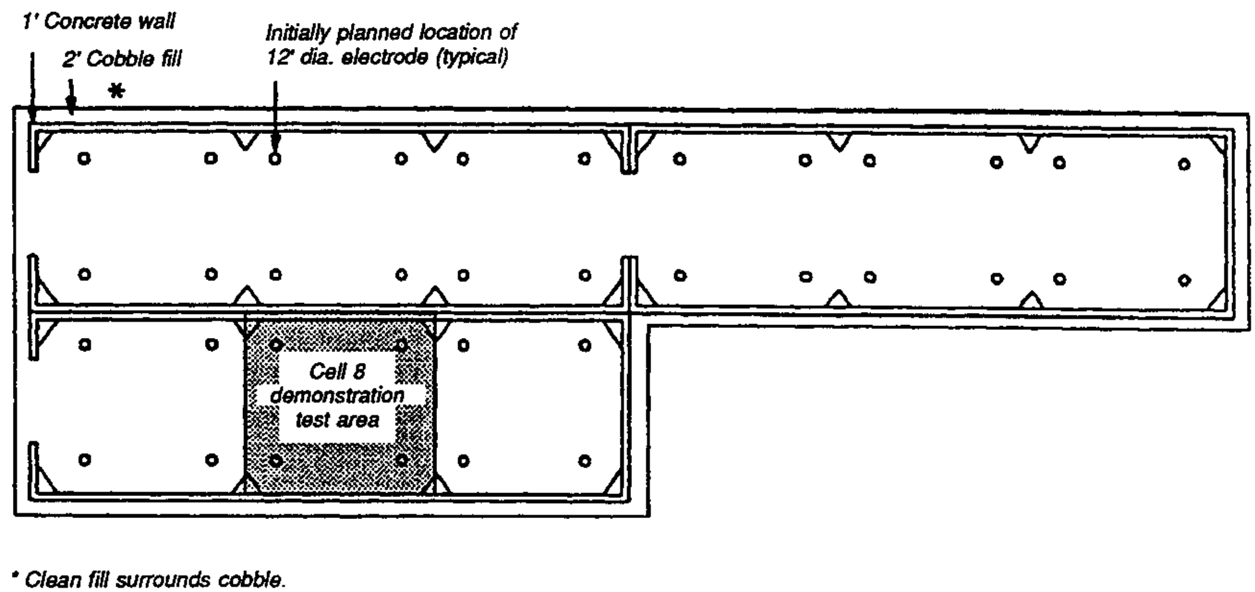


Figure 3. Plan view of treatment cells.

released by this decomposition. The cobble outside of the cells created porous paths in the vicinity of treatment, thereby increasing the likelihood of vapors escaping the area outside the hood and causing irregular melt shapes.

Geosafe responded by excavating the area outside of the remaining treatment cells and removing the particle board forms. A refractory ceramic material with insulating and reflective properties was placed adjacent to the exterior of the concrete cell walls. This helped to control the melt shape, limit fugitive vapor emissions, and restrict the melt energy inside the cell boundaries. Based upon the experience Geosafe gained at the Parsons site, the design and construction of staged treatment cells will be modified for future projects. It should be noted that the use of cobble in treatment cell construction was unique to the Parsons site where the configuration and flow of the on-site groundwater dictated its application.

Utility requirements for this technology include electricity, natural gas (if a thermal oxidizer is used), and water. As expected, electricity is a major consideration when implementing ISV. Total power to the electrodes during treatment is approximately three MW; the voltage applied to each of the two phases during steady state processing averages around 600 volts while the current for each phase averages approximately 2,500 amps. During treatment of the Demonstration Test cell (Cell 8), energy to the electrodes totalled 613 MWh. Energy demands for other cells at the Parsons site differed—primarily because of variations in the soil moisture content.

Process Residuals

The primary residual generated by the Geosafe ISV technology is the vitrified soil product. This material is generally left intact and in place at the conclusion of treatment. The treated volume may take one to two years to cool completely.

A number of secondary process waste streams are generated by the Geosafe technology. These include air emissions, scrubber liquor, decontamination liquid, carbon filters, scrub solution bag filters, HEPA filters, used hood panels, and personal protective equipment (PPE). Gaseous emissions which meet regulatory requirements are discharged directly to the atmosphere following treatment. The amount of scrubber liquor and filter waste generated depends on the nature of the treatment media. Factors such as high off-gas particulate loading and high soil moisture content may result in large quantities of these materials. The number of used hood panels requiring disposal depends on the type and extent of contamination at the site, the corrosiveness of the off-gases generated during treatment (as well as the corrosion-resistance of the hood panels), and the duration of treatment.

Some process residuals (e.g., used scrub solution bag filters, HEPA filters, and PPE) can be disposed in subsequent melt settings to reduce the volume of these materials requiring ultimate disposal off-site. Scrubber water generated during treatment may require special handling depending upon the type and level of contaminants being treated.

Performance Data

The Geosafe ISV technology was evaluated to determine its effectiveness in treating soil contaminated with pesticides and metals. Cell 8 was selected for the Demonstration Test since it exhibited the highest levels of contamination whereby demonstration objectives could be evaluated. The critical objective for this project was to determine if final soil cleanup levels set by the EPA Region V could be achieved. These specified cleanup levels included 1,000 µg/kg for chlordane, 4,000 µg/kg for 4,4'-DDT, 80 µg/kg for dieldrin, and 12,000 µg/kg for mercury. Non-critical objectives for this project were:

- to evaluate the leachability characteristics of chlordane, 4,4'-DDT, dieldrin, and mercury in the pretreatment soil using the toxicity characteristic leachability procedure (TCLP) and determine whether the leachability characteristics of these compounds in the vitrified residue meet the regulatory limits specified in 40 CFR §261.24. (Note: only chlordane and mercury are listed.);
- to determine the approximate levels of dioxins/furans, pesticides (specifically chlordane, 4,4'-DDT, and dieldrin), mercury, and moisture in the pre-treatment soil;
- to characterize the liquid residues (scrubber water) of the process with respect to pesticide and mercury concentrations;
- to evaluate emissions from the process;
- to identify the operational parameters of the technology;
- to develop operating costs and assess the reliability of the equipment; and
- to examine potential impediments to the use of the technology including technical, institutional, operational, and safety impediments.

Approximately 3,000 yd³ (5,400 tons) of contaminated soil was excavated and staged into nine treatment cells. Prior to treatment, three primary soil cores were obtained from Cell 8 to characterize the concentrations of pesticides, dioxins/furans, and metals. Samples were also collected to determine the leachability characteristics of pesticides and mercury before treatment. In addition, samples were taken for the analysis of grain size, moisture, density, and permeability. Prior to treatment, potable water was charged to the scrubber system, and then sampled and analyzed for volatile and semivolatile organic compounds, pesticides, dioxins/furans, and metals. The scrubber water was again sampled and analyzed for these parameters during treatment.

Samples of the stack gas were collected during treatment. The samples were analyzed for volatiles, semivolatiles, pesticides, dioxins/furans, metals, hydrogen chloride, and particulates. The stack gas was also monitored for oxygen, carbon monoxide, and total hydrocarbons using continuous emission monitors.

System parameters including, but not limited to, voltage and amperage applied to the molten soil, hood vacuum, and off-gas treatment train operational attributes, were monitored during treatment. Measurements were taken every minute and recorded by computer. Additional parameters such as hood skin and plenum temperatures, scrubber pH and volume, and differential pressures across the scrubber system and filters were manually recorded regularly.

Three primary post-treatment vitrified soil samples were collected from the surface of Cell 8. Analysis of the surface samples was intended to provide immediate information regarding the condition of the soil until samples more representative of the center of the treatment area can be safely obtained. Additional sampling is scheduled to be performed after the molten mass has sufficiently cooled (in approximately one yr). The surface samples collected immediately after treatment were analyzed for pesticides, dioxins/furans, and metals. The TCLP was also performed on these samples to determine the leachability of the treated soil. Post-treatment samples were collected from the scrubber water and analyzed for volatiles, semivolatiles, pesticides, dioxins/furans, and metals.

Table 2 summarizes the range of selected analytical results from samples collected during the Demonstration. Because of the limited number of samples collected, ranges are presented rather than average values. The data presented in this table are limited to analytes that were of concern during the Demonstration and important in evaluating test objectives. Concentrations below the respective reporting detection limits are indicated by a "less than" symbol (i.e., <).

Evaluation of the data suggests the following results and conclusions:

- The technology successfully treated the soil, completing the test cell melt in ten days with only minor operational problems. During this time, approximately 330 yd³ (approximately 600 tons) of contaminated soil was vitrified, according to Geosafe melt summaries. Approximately 613 MWh of energy was applied to the total soil volume (estimated to be 475 yd³) during vitrification of Cell 8; energy applied to the actual contaminated soil volume could not be independently measured because clean fill and surrounding uncontaminated soil are vitrified as part of each melt. System operation was occasionally interrupted briefly for routine maintenance such as electrode system addition and adjustment.

- The treated (vitrified) soil met the EPA Region V cleanup criteria for pesticides and mercury. Target pesticides were reduced to levels below their analytical reporting detection limits (<80 µg/kg for chlordane, <16 µg/kg for 4,4'-DDT and dieldrin) in the treated soil. Mercury, analyzed by standard SW-846 Method 7471 procedures, was reduced to less than 40 µg/kg in the treated soil. Although the concentration of pesticides and mercury were below the cleanup criteria in some samples, significant contaminant reductions were achieved. Chlordane was not detected in any of the

Table 2. Selected Data Summary Results

Pesticides	*Chlordane*	*4,4' DDT*	*Dieldrin*
Pre-Treatment Soil (µg/kg)	*<80*	*2,400 - 23,100*	*1,210 - 8,330*
Post-Treatment Soil (µg/kg)	*<80*	*<16*	*<16*
Pre-Treatment TCLP (µg/L)	*<0.5*	*0.120 - 0.171*	*6.5 - 10.2*
Post-Treatment TCLP (µg/L)	*<0.5*	*<0.1*	*<0.1*
Stack Emissions (µg/m³)	*<1.38*	*<0.28*	*<0.28*
Stack Emissions (lb/hr)	*<1.1 X 10^{-5}*	*<2.2 X 10^{-6}*	*<2.2 X 10^{-6}*

Metals	*Arsenic*	*Chromium*	*Lead*	*Mercury*
Pre-Treatment Soil (µg/kg)	*8,380 - 10,100*	*37,400 - 47,600*	*<50,000*	*2,220 - 4,760*
Post-Treatment Soil (µg/kg)*	*717 - 5,490*	*12,500 - 14,600*	*<5,000 - 21,000*	*<40*
Pre-Treatment TCLP (µg/L)	*NA*	*NA*	*NA*	*<0.2*
Post-Treatment TCLP (µg/L)	*<4 - 30.5*	*<10 - 17.1*	*<50 - 4,290*	*<0.2 - 0.23*
Stack Emissions (µg/m³)	*<0.269*	*2.081 - 3.718*	*<3.891*	*12.9 - 17.7*
Stack Emissions (lb/hr)	*<12.93 X 10^{-6}*	*1.48 X 10^{-5} 2.67 X 10^{-5}*	*<2.82 X 10^{-5}*	*9.89 X 10^{-5}- 1.25 X 10^{-4}*

< *Indicates that analyte was not deteced at or above the reporting detection limit (value presented).*
* *Values presented were obtained using standard SW-846 digestion and analytical methods. These soil methods are EPA-approved, however, other non-approved methods may provide more accurate metal determinations for vitrified materials.*
NA *Indicates that the sample was not analyzed for this parameter.*

SITE Demonstration samples, but were detected in samples collected by EPA Region V.

- The solid vitrified material collected was subjected to TCLP for pesticides and mercury. No target pesticides were detected in the leachate; the average leachable mercury was approximately 0.2 µg/L, well below the regulatory limit of 200 µg/L (40 CFR Part 261.24).

- Stack gas samples were collected during the Demonstration Test to characterize process emissions. There were no target pesticides detected in the stack gas samples. During the Demonstration Test, mercury emissions averaged 16 µg/m³ (1.1 x10⁻⁴ lb/hr). The emissions were below the regulatory requirement of 88 µg/m³ (5.93 x 10⁻⁴ lb/hr). Other metal emissions in the stack gas (specifically arsenic, chromium, and lead) were monitored and found to meet regulatory standards during testing. Stack gas dispersion modeling by Region V indicated that metal emissions during treatment were not a human health risk.

- Emissions of total hydrocarbons and carbon monoxide were regulated at 100 ppmV (as propane) and 150 ppmV, respectively. Throughout the Demonstration Test, vapor emissions of these gases (measured downstream from the thermal oxidizer) were each consistently below 10 ppmV—well below the regulatory guidelines.

- Scrubber water generated during the Demonstration Test contained volatile organics, partially oxidized semivolatile organics (phenolics), mercury, and other metals. The scrubber water underwent secondary treatment off-site before ultimate disposal and data suggest that secondary treatment of this waste stream is likely in most cases.

- Pre-treatment soil dry density averaged 1.48 tons/yd³, while post-treatment soil dry density averaged 2.10 tons/yd³. On a dry basis, a volume reduction of approximately 30 % was observed for the test soil.

Key findings from the demonstration, including complete analytical results and the economic analysis, will be published in an Innovative Technology Evaluation Report. This report will be used to evaluate the Geosafe ISV Technology as an alternative for cleaning up similar sites across the country. Information will also be presented in a SITE Demonstration Bulletin and a videotape.

Economic Analysis

Estimates on capital and operating costs have been determined for a treatment volume of approximately 3,200 yd³ (5,700 tons). This is slightly higher than the total treatment volume at the Parsons site, but it is based on the treatment configuration used at this site (nine treatment cells measuring 27 ft by 27 ft by 15 ft deep with 2 ft of clean fill on top of the contaminated soil). This information was extrapolated to determine a treatment cost for remediating approximately 970 yd³ (nine treatment cells measuring 27 ft by 27 ft by 5 ft deep with 1 ft of clean fill) and approximately 4,400 yd³ (nine treatment cells measuring 27 ft by 27 ft by 20 ft deep with 2 ft of clean fill). The cost for the treatment of approximately 3,200 yd³ (5,700 tons) of soil is based on the SITE demonstration at the Parsons site and is estimated to be approximately $780/yd³ ($430/ton). For lesser volumes of soil (970 yd³, as described above), the cost becomes approximately $1,500/yd³ ($850/ton). For larger volumes of soil (4,400 yd³, as described above), the cost becomes approximately $670/yd³ ($370/ton). The primary determinants of cost are the local price of electricity, the depth of processing, and the soil moisture content. Treatment volume (and therefore treatment time) is the key variable between the costs of these three cases. The cost of time-dependent factors including equipment rental, labor, consumables and supplies, and utilities varies directly with treatment time.

The primary cost categories include utilities, labor, and startup and fixed costs, each contributing roughly 20% to the total cost (utilities slightly higher). The contribution of utilities increases markedly with increased treatment volume. Equipment costs and facilities modifications and maintenance costs are each responsible for roughly 10% of the total treatment cost. Treatment is most economical when treating large sites to maximum depths, particularly since time between melts is minimal compared to actual treatment time.

The cost for treatment using the Geosafe ISV technology is based on, but not limited to, the following assumptions:

- The contaminated soil is staged into treatment cells by an independent contractor prior to Geosafe's arrival on-site. Cell preparation and construction are site-specific and may be different for each case, however, it is assumed that each site is prepared in a manner similar to the Parsons site.

- The depth of treatment is assumed to exceed the depth of contamination by at least one ft to ensure that the melt incorporates the floor of the cell and beyond.

- Treatment takes place 24 hr/day, 7 days/wk, 52 wk/yr. An on-line efficiency factor of 80% has been incorporated to account for down-time due to scheduled and unscheduled maintenance and other unforeseen delays.

- Operations for a typical shift require one shift engineer and one operator. In addition, one site manager and one project control specialist are present on-site during the day shift. Three shifts of workers are assumed to work eight hr/day, seven day/wk for three weeks. At the end of three weeks, one shift of workers is rotated out, and a new set replaces the former.

- The costs presented (in dollars/cubic yard) are calculated based on the number of cubic yards of contaminated soil treated. Because clean fill and surrounding uncontaminated soil are treated as part of each melt, the total number of cubic yards of soil treated is higher than the number of cubic yards of contaminated soil treated. Costs/cubic yard based on total soil treated would, therefore, be lower than the costs presented in this estimate.

If Geosafe scales its process differently than assumed in this analysis (a likely scenario), then the cost of remediation/cubic yard of contaminated soil will change.

These cost estimates are representative of charges typically assessed to the client by the vendor and do not include profit. The costs presented in this economic analysis are based upon data gathered at the Parsons site. The developer claims these costs were unusually high, and expects the treatment costs for future sites to be less than the treatment costs for the Parsons site. A detailed explanation of these costs is included in the Innovative Technology Evaluation Report.

Technology Status

The technology was originally developed by Pacific Northwest Laboratory, operated by Battelle Memorial Institute, and has been undergoing testing and development since 1980. A majority of the development work was performed the U.S. Department of Energy, however, significant work also has been done for various private and other government sponsors. The technology has been licensed exclusively to Geosafe Corporation for the purpose of commercial applications of hazardous and radioactive waste remediation. To date, the technology has been tested on a wide variety of hazardous chemical, radioactive, and mixed wastes. Treatability tests are typically conducted on an engineering scale (100 to 200 lb melts) to determine potential applicability of the technology. Geosafe has also conducted full-scale in situ operational acceptance tests at their facility in Richland, WA. The work performed at the Parsons site was the first commercial full-scale application of the ISV technology.

The Records of Decision for five U.S. Department of Defense and EPA-lead Superfund sites (including the Parsons site) have identified ISV technology as the preferred remedy for cleanup. ISV also has been identified as an alternative cleanup option at two additional sites. Currently, Geosafe is scheduled to perform full-scale remediation activities for other customers at sites contaminated with PCBs, chlorinated organics, and toxic metals. Treatment at each of these sites involves some amount of debris or otherwise foreign materials. In situ or staged in situ configurations will be used for the planned remediations.

Higher levels of contamination at other sites are not expected to represent a significant challenge to the process. For these sites, it may be possible to obtain destruction and removal efficiencies (DRE) if contaminants are present at high enough levels. DRE calculations were not possible at the Parsons site due to the low levels of target organics.

Operational parameters that affect the overall process performance have a much larger influence on successful application of ISV than contamination levels. Factors such as high soil moisture, extreme depths (deep or shallow), the presence of sealed drums, and soil composition are the primary factors that influence remedial design and operation. With proper management, it is anticipated that the process may successfully be applied at other sites with higher levels of contamination.

SITE Program Description

In 1980, the U.S. Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. CERCLA was amended by the Superfund Amendments and Reauthorization Act (SARA) in 1986. The SITE Program is a formal program established in response to SARA. The primary purpose of the SITE Program is to maximize the use of alternatives in cleaning up hazardous waste sites by encouraging the development and demonstration of new, innovative treatment and monitoring technologies. It consists of four major elements: the Demonstration Program, the Emerging Technology Program, the Monitoring and Measurement Technologies Program, and the Technology Transfer Program. The Geosafe ISV Technology was demonstrated under the Demonstration Program. This Capsule was published as part of the Technology Transfer Program.

Disclaimer

While the technology conclusions presented in this report may not change, the data has not been reviewed by the Quality Assurance/Quality Control office.

Sources of Further Information

EPA Contacts:

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2950 George Washington Way
Richland, WA 99352
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Fax No.: 509/375-7721

References

Hansen, James E. 1993. "In Situ Vitrification (ISV) for Remediation of Contaminated Soil Sites." Geosafe Corporation. Richland, WA.

SAIC. 1993. "Geosafe In Situ Vitrification Demonstration Plan; Superfund Innovative Technology Evaluation." Science Applications International Corporation. San Diego, CA.

USEPA. 1992. *Handbook on Vitrification Technologies for Treatment of Hazardous and Radioactive Waste.* EPA/625/R-92/002. U.S. Environmental Protection Agency. Office of Research and Development. Washington, D.C.

APPENDIX C

Table 6.1. Alternatives Performance Summary, Rocky Flats

Table 6.1 Alternatives Performance Summary

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
	Pump liquids/ excavate solids/ immobilize/tre and dispose offsite	Pump liquids/excavate solids/treat and dispose onsite	In situ soil heating/in situ bioremediation/ RCRA cap	In situ soil heating/ISV
Long-term effectiveness and permanence	4	4	3	5
Ease of compliance with requirements	3	3	4	5
Reduction of toxicity, mobility, or volume	2-3	3	3-4	4-5
Short-term effectiveness	3	3	4	4
Schedule	2	1	3	3
Implementability	4	2	3	3
Cost	1	1	5	4
Sensitivity of treatment to waste form	4	4	3	4
Leveraging for other contaminated sites	2	4	4	4
Overall rank	**25-26**	**25**	**32-33**	**36-37**

APPENDIX D

Communications with Geosafe. Re: ISV Applicability to OU 7-13/14

Idaho National Engineering Laboratory

September 11, 1995

Mr. James E. Hansen
Director, Business Development & Communications
Geosafe Corporation
2950 George Washington Way
Richland, Washington 99352

REQUEST FOR INFORMATION ON IN SITU VITRIFICATION (ISV) IN SUPPORT OF A REMEDIAL INVESTIGATION/FEASIBILITY STUDY FOR THE IDAHO NATIONAL ENGINEERING LABORATORY - WJP-18-95

Dear Mr. Hansen:

The Idaho National Engineering Laboratory (INEL) is currently gathering data on available remediation technologies for the treatment of mixed and radioactive waste currently buried at the Sub-Disposal Area (SDA) of the Radioactive Waste Management Complex (RWMC). This effort is in support of a Remedial Investigation/Feasibility Study (RI/FS) for the buried waste contained in pits, trenches and soil vaults of the SDA. The title of this waste site is Operating Unit 7-13/14 (OU 7-13/14) at the SDA of the INEL. The present (draft) schedule calls for approval of the Record of Decision (ROD) for remediation of OU 7-13/14 by September, 1998.

As per U. S. EPA guidelines for conducting feasibility studies under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), our initial effort seeks to identify and gather information on all technologies that may be applicable to remediation of OU 7-13/14, while a later phase of the feasibility study will focus on putting various technologies together into systems and evaluating in detail the remediation alternatives.

We are requesting with this letter that Geosafe Corporation supply the INEL with information on In Situ Vitrification for this purpose. We have identified In Situ Vitrification as a technology that is believed to be potentially capable of treating either all or a portion of this waste based upon our review and preliminary assessment of available treatment technologies. A draft statement of remediation goals and a summary of site characteristics is attached.

Information is needed in two stages. In order to plan the full scope of the feasibility study, answers to the following questions are needed by September 19:

1. Is site characteristic data (in addition to that attached) needed in order to determine technology performance? If so, please describe what characterization data is needed.

2. Will treatabilty studies be required to obtain performance data for the technology? If so, what is the overall scope for treatability studies?

3. Will pilot plant or full scale tests be needed to further verify performance data for the technology applied to the INEL OU 7-13/14 site? If so, briefly describe tests needed.

Additional information, as per the attached form, is requested by October 20 to help us in performing the feasibility study for OU 7-13/14. You are encouraged to provide any additional information which you believe can be used to evaluate In Situ Vitrification's overall effectiveness. It is desired, but not a mandatory requirement that this technology be commercially developed and/or demonstrated on hazardous or mixed waste at this time. This technology should, however, be sufficiently developed to ensure that is can be demonstrated in a pilot plant scale mode of operation by the scheduled ROD completion date.

If you have any questions or need additional explanation to fulfill this request, please call Jack Prendergast at (208)-526-8221 or contact me by electronic mail at wjp@inel.gov.

Sincerely,

Jack Prendergast, P.E., DEE
Advisory Engineer,
LockHeed-Martin Idaho Technologies

Attachments:

1. OU 7-13/14 Remediation Goals
2. OU 7-13/14 Characterization Information Summary
3. Requested Information for Technology

ATTACHMENT 1

IDAHO NATIONAL ENGINEERING LABORATORY SUBSURFACE DISPOSAL AREA PITS AND TRENCHES (OU 7-13/14) REMEDIATION OBJECTIVES (DRAFT)

1. Prevent contaminant migration into the Snake River Plain aquifer.

2. Prevent contaminant migration into INEL and other local water supply sources.

3. Prevent human exposure to contaminants as a result of biotic transport of contaminants from the buried waste to the surface.

4. Remediate site media (soil and waste) to risk-based contaminant levels (TBD).

5. Minimize on-site worker exposure to chemical and radiological waste contaminants during and subsequent to remediation.

6. Comply with all applicable Federal and State of Idaho requirements, including (but not limited to) the Hazardous Waste Management Act, the Resource Conservation and Recovery Act, the Clean Air Act, and the Toxic Substances Control Act.

7. Contain, treat or remove contaminants and/or contaminated media in a cost/effective manner, considering all remediation, waste disposal, and long-term waste storage costs.

Major radiological contaminants: Sr-90, Cs-137, Am-241, I-129, C-14, Pu-239, Pu-240, Ni-63, Tc-99, Nb-94, Ra-226, H-3, Pu-241, Pu-238, Cl-36, U-238, Np-237, Ni-59, Co-60, U-234, Eu-154, Eu-152, U-235, Am-243, U-236, Pu-242, Na-22, U-233, U-232, Th-232, Cm-244

Major nonradiological contaminants: Asbestos, hydrazine, nitrate salts, mercury, acetone, carbon tetrachloride, cadmium, uranium, lead, sodium cyanide, tetrachloroethylene, 2-butanone, beryllium, dichloromethane

ATTACHMENT 2

OU 7-13/14 CHARACTERIZATION - Summary

Waste Volume, Density and Weight

Volume: 6.8 million ft^3 (2.2 million ft^3 of TRU waste plus 4.6 million of low-level waste)
Density: 40 lb/ft^3
Weight: 272 million pounds

Soil Volume and Weight

Estimated Contaminated Soil Volume: 10 million ft^3 (soil intermingled with waste plus underburden plus 1.7 million ft^3 areas adjacent to waste)
Estimated Noncontaminated Soil Volume: 10 million ft^3 (overburden plus about 25% additional for soil in between waste areas and adjacent to waste areas)
Estimated Contaminated Soil Weight: 1 billion pounds
Estimated Noncontaminated Soil Weight: 1 billion pounds

Waste Description

See attached Table 1
Addtional descriptive information available upon request

Waste Composition and Physical Forms

Estimated Combustible Content:	20 wt%
Estimated Metal Content:	30 wt%
Other:	50 wt%

Estimated Number of Drums:	480,000 (mostly 55-gal, some 40- and 30-gal)
Estimated Number of Wooden Boxes:	20,000 (mostly 7- by 4- by 4-ft)
Estimated Number of Cardboard Boxes:	60,000 (various sizes)
Estimated Number of Other Containers:	4,000

Waste also includes large, loose items (trucks, vessels, heat exchangers, etc.)
High percentage of containers are expected to be deteriorated or breached

Nonradiological Contaminants

Major contaminants (by risk): Asbestos, hydrazine, nitrates, mercury, acetone, carbon tetrachloride, cadmium, uranium, lead, sodium cyanide, tetrachloroethylene, 2-butanone, beryllium, methylene chloride

Major contaninants (by quantity): Sodium nitrate ($2x10^6$ lbs), lead ($1.3x10^6$ lbs), potassium nitrate ($1x10^6$ lbs), uranium ($6x10^5$ lbs), aluminum nitrate nanohydrate ($4.2x10^5$ lbs), carbon tetrachloride ($2.6x10^5$ lbs), 1,1,1 trichloroethane ($2.4x10^5$ lbs), trichloroethylene ($2.4x10^5$ lbs), nitric acid ($1.1x10^5$ lbs)

Expected forms: See attached Table 2

Additional information on nonradiological contaminants is available

Radiological Contaminants

Major radiological contaminates (by risk): Sr-90, Cs-137, Am-241, I-129, C-14, Pu-239, Pu-240, Ni-63, Tc-99, Nb-94, Ra-226, H-3, Pu-241, Pu-238, Cl-36, U-238, Np-237, Ni-59, Co-60, U-234

Major radiological contaninants (by quantity): U-238 ($5.9x10^5$ lbs), U-235 ($7.1x10^3$ lbs), Pu-239 ($2.4x10^3$ lbs), Pu-240 (150 lbs) Ni-59 (130 lb) Am-241 (100 lbs), Ni-63 (24 lb), Cs-137 (16 lb), C-14 (10 lb), Pu-241 (8 lb), Sr-90 (7 lb), Np-237 (6 lb), Co-60 (5 lb)

Radiological contaminants - chemical forms

Additional information on radiological contaminants is available

Soil Properties (Properties are based on available data and may not be truly representative nor cover the full range of variation over the entire site)

Porosity: Average 44%, Range 21-58%

Specific Gravity: Average 2.61, Range 2.44-2.73

Bulk Density: Average 100 lb/ft^3, Range 69-131 lb/ft^3

Moisture Content: Average 12.3 wt%, Range 0-21 wt% (Note: moisture varies with depth, with time of year, and with location within the SDA)

Particle Size Distribution:

	Average	Range
<4 micron	33%	0-90%
4-62 micron	60%	0-80%
62-2000 micron	7%	3-100%

Note: Particle size varies widely, additional information is available

Vertical Hydraulic Conductivity: Range: 1.0×10^{-8} - 6.2×10^{-4} cm/sec

Cation Exchange Capacity: Average: 21.6 meq/100 g, Range: 14-30 meq/100 g

Atterburg Limits

Liquid Limit:	26.0-43.4%
Plastic Limit:	20.0-24.0%
Plasticity Index:	6.0-21.2%

Shear Strength
Cohesion: 1950 - 8055 kg/m^3
Friction Angle: 22-58°

Mineral Content (based on very limited sampling)

Clay	10-70%
Quartz	15-30%
Calcite	0-41%
Plagioclase	6-12%
Potassium feldspar	<3-5%
Pyroxene	4-9%

Carbonate Content: 0-63%

Table 1. Wastes known to be present in SDA pits and trenches.

Construction and Demolition Material	Lumber, wallboard, concrete, steel plate, ducting, electrical wires, fuse boxes, roofing material, floor tile, insulation, lead sheet, lead brick, asphalt paving materials, soil, sand, gravel, steel stairways, ladders, plexiglas, leaded glass, glove boxes, asbestos, Benelex
Laboratory equipment and materials	Hoods, laboratory benches, desks, chairs, cabinets, glassware, plastic tubing, plastic and glass bottles, solutions stabilized in concrete or plaster, vermiculite, steel-copper crucibles, rubber hose, acid carboy, uranium film sampler, glovebox gloves, syringes, gas cylinders
Process equipment and materials	Air compressor, tanks, heat exchangers, tube bundles, condensers, piping, flanges, valves, ion exchange resins and columns, demineralizer, pumps and pump parts, motors, continuous air monitors, air conditioner, furnace coke, carbon baffles, HEPA filters, Raschig rings, electronic tubes and instruments, control panels, dissolver pots, drums of organic solvents (including halogenated, nonhalogenated, organophosphates, and mixtures of types), uncemented sludges
Nuclear reactor components, fuel, and radioactive sources	Irradiated hardware, core structural components, fuel scraps, fuel rods, graphite cuttings, reactor core, beryllium reflectors, Ra-226 and other sources, reactor vessel, fuel end pieces, Co-60 wires in concrete, irradiated fuel powder and pellets, Pu-coated disks, 55-gal drums embedded in 60-70 ft^3 of concrete shielding
Maintenance equipment and scrap metals	Hand tools, metal-working machines, drill presses, cranes, hoists, welders, oil and grease, metal filings, abrasive wheels, lathes, drum of machine coolant, scrap metals (Ag, Al, Be, Cd, Cu, Fe, K, Mg alloy, Mg-Th, Na, NaK, Pb, Sn, depleted Uranium, Zr and Zr alloys, others), backhoe parts
Decontamination Materials	Paper, rags, plastic bags and sheet, floor sweepings, brooms, steel wool, coveralls, hardhats
Miscellaneous	Sewer sludge, garbage, tires, lunchbox, animal tissue, carcasses, feces, botulinus-contaminated meat, jet engine, dump truck, trailers, forklift, pickup trucks, tanker, magnesium fluoride slag, solidified $CeCl_3$ solution, boric acid crystals, solidified evaporator sludge, contaminated mud, office equipment, lead-acid batteries, mercury batteries, barrels of Santo-R wax, tires, safe, camera, radios, casks, concrete cask with steel liner filled with solidified sludge, pyrophoric zirconium and uranium metal fines

Table 2. Chemical and Physical Forms of Nonradiological Contaminants.

	Physical waste form	Chemical form
Ammonia	liquid in pressurized bottles	NH_3
Asbestos	loose scrap in soil	asbestos fibers
Beryllium	metal reflectors	Be metal
Cadmium	metal and miscellaneous	Cd metal
HF	liquid in soil neutralized with lime	HF and various metal complexes
Hydrazine	disposed of as anhydrous hydrazine in soil (acid pit)	N_2H_4
Lead	lead acid batteries, scrap metal, bricks, leaded gloves, leaded aprons, drum and cask linings, and other forms	Pb metal
Mercury	neutralized liquids in soil; mercury batteries	$Hg(NO_3)_2 \cdot H_2O$
Nitrate	solids and sludges in drums or solutions in soil	$NaNO_3$, KNO_3, $Al(NO_3)_3 \cdot 9H_2O$, $UO_2(NO_3)_2$, $Hg(NO_3)_2 \cdot H_2O$, $Cu(NO_3)_2$
Nitric acid	liquid in soil	$HNO_{3(aq)}$
Tetrachloro-ethylene, TCE, TCA, carbon tetrachloride,	liquids, with other organics, absorbed on calcium silicate and packaged in drums	C_2Cl_4, C_2HCl_3, $C_2H_3Cl_3$, CCl_4
Tributyl phosphate	liquid in soil	$(C_3H_9O)_3PO$
Uranium	nitrate solution in soil, scrap metal, fuel scraps, metal alloys, solution absorbed in vermiculite, hot cell wastes depleted uranium turnings in oil and sawdust, metal fines, irradiated test fuels	U metal, alloys, uranyl nitrate, oxides, carbide

Table 3. Chemical and Physical Forms of Major Radiological Contaminants.

	Physical waste form	Chemical forms[a]
Sr-90	Irradiated fuel in metal liner, contaminated rubble and combustibles in soil or cardboard boxes	ABS
Cs-137	Metal waste, combustible waste, HEPA filters, canal sludge, irradiated fuel, rubble in cardboard boxes, steel boxes, concrete casks, wooden boxes or no container	ABS, urea-formaldehyde solidified sludge
Am-241	Unsolidifed sludge, rubble, combustibles, miscellaneous in metal drums	ABS
C-14	Reactor vessel, core, and associated parts	AP
Pu-239,-240, -241,-238	Metal, rubble, HEPA filters, resins, combustibles, sludges,	ABS, metal, oxides on/embedded in ceramic, AP in concrete and others
Ni-63, Ni-59	Vessel, metal, rubble, fuel, combustibles, resin	ABS, AP
Nb-94	Reactor vessel, core, and associated parts	AP
Ra-226	Biological waste, metal, fuel, combustibles	ABS, AP, AP embedded in concrete
H-3	Be metal waste	
U-238	Combustibles, salts, rock, HEPA filters, rubble, other	ABS, salt compounds, minerals
Np-237	Metal, rubble	ABS, AP
Co-60	Metal, irradiated fuel, rubble Reactor vessel, other	AP, ABS

[a] "ABS" indicates oxides, hydroxides, nitrates, particulates, etc., sorbed or bonded to surfaces of waste medium; "AP" indicates an activation product in metal waste

ATTACHMENT 3

REQUESTED INFORMATION FOR TECHNOLOGY

Technology Trade Name: ______________________________________
Company (Vendor) Name: ______________________________________
Company Address: ______________________________________
Contact Person(s): ______________________________________
ContactTitle(s): ______________________________________
Phone Number(s): ______________________
FAX Number(s): ______________________
Electronic Mail ID(s): ______________________

Nonproprietary description of technology:

Applicability to OU 7-13/14 waste:

1. Based on the attached waste/soil description (Attachment 2), are there waste forms or types that could not be treated by your technology? If so, pleas list.
2. Based on the attached waste/soil description (Attachment 2), are there pretreatment requirements such as sorting, sizing, separations, etc. in order to effectively utilize your technology to treat the OU 7-13/14 waste? If so, please describe.
3. Has your technology been used to remediate radioactive waste sites? If so, what are typical worker exposure rate? If not, please state how adaptable the technology would be to a radiation enviroment (feasibility of remote operation, reliability, maintenance requirements, etc.).

Performance Measurements
(Specific to each technology, see EDF for starting point)

Commercial Capacity Range

Number of Commercial Facilities
Operating
In Planning or Design Phases

Representative Projects (Commercial, pilot, or demonstration): (List by specific project, location, waste application, point of contact for reference, quantity of waste treated, feed rate of treatment remediation, on-stream time as a percentage, unit cost for treatment experienced, and actual performance data of contaminant(s) level before and after treatment)

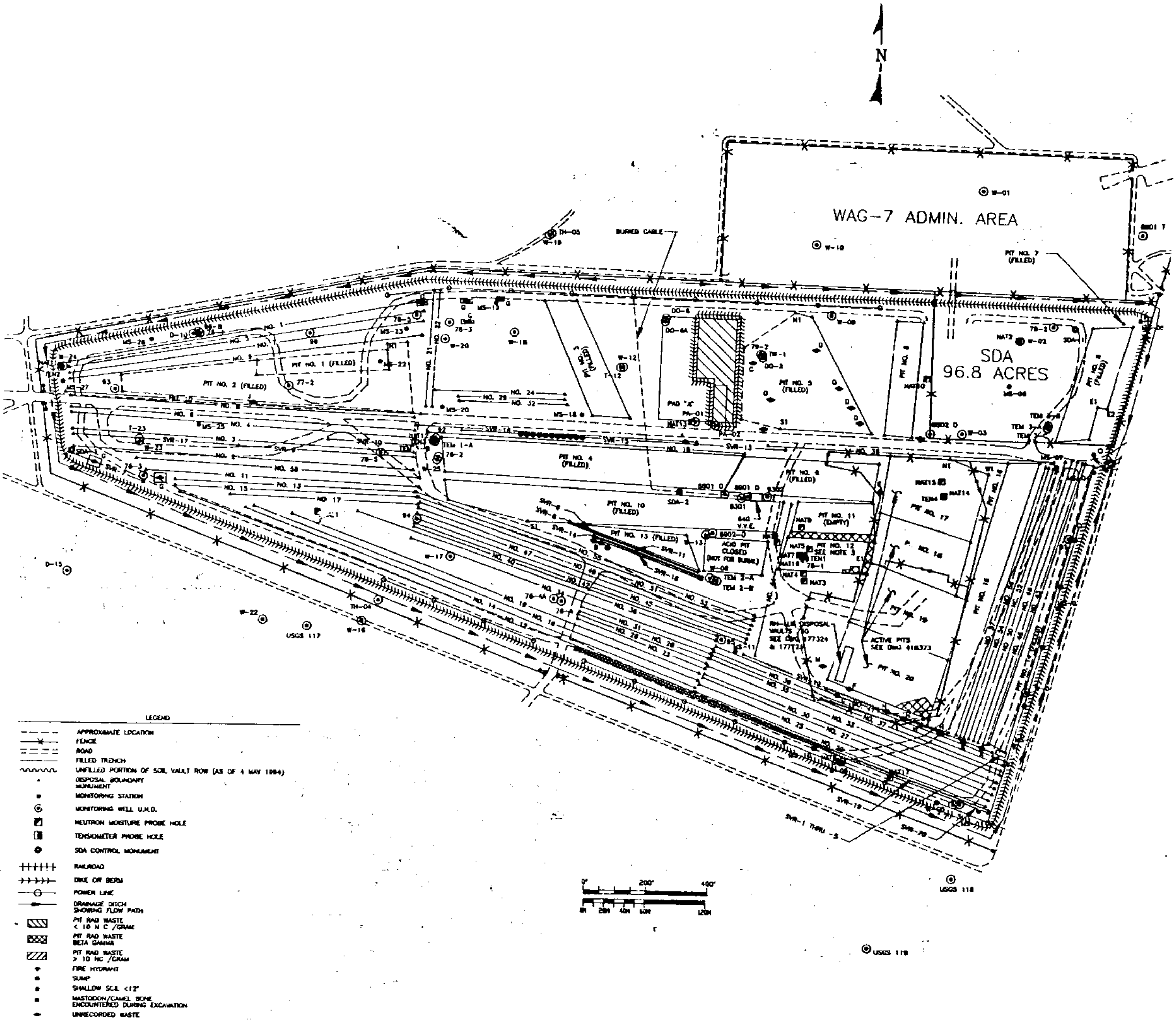
Development Plans: (Specify the current status of the technology and the development plans for employing it on radioactive or mixed waste applications.)

Utilities requirements:

Costs:

Demonstration and testing cost estimate:
Order of magnitude capital cost, based on 10 year remediation of OU 7-13/14:
Operating costs:

Additional information: (List any features of not given above that make this technology unique or an improvement over others.)


N
WAG-7 ADMIN. AREA
SDA
96.8 ACRES
BURIED CABLE
PIT NO. 1 (FILLED)
PIT NO. 2 (FILLED)
PIT NO. 4 (FILLED)
PIT NO. 5 (FILLED)
PIT NO. 6 (FILLED)
PIT NO. 7 (FILLED)
PIT NO. 10 (FILLED)
PIT NO. 11 (EMPTY)
PIT NO. 12 SEE NOTE 3
PIT NO. 13 (FILLED)
PIT NO. 20
PAD "A"
ACID PIT CLOSED (NOT FOR BURIAL)
RH-LLW DISPOSAL VAULTS SEE DWG 177324 & 177328
ACTIVE PITS SEE DWG 418373
SVR-1 THRU -5
USGS 117
USGS 118
USGS 119
0' 200' 400'
LEGEND
APPROXIMATE LOCATION
FENCE
ROAD
FILLED TRENCH
UNFILLED PORTION OF SOIL VAULT ROW (AS OF 4 MAY 1994)
DISPOSAL BOUNDARY MONUMENT
MONITORING STATION
MONITORING WELL U.N.D.
NEUTRON MOISTURE PROBE HOLE
TENSIOMETER PROBE HOLE
SDA CONTROL MONUMENT
RAILROAD
DIKE OR BERM
POWER LINE
DRAINAGE DITCH SHOWING FLOW PATH
PIT RAD WASTE < 10 N C /GRAM
PIT RAD WASTE BETA GAMMA
PIT RAD WASTE > 10 NC /GRAM
FIRE HYDRANT
SUMP
SHALLOW SOIL <12"
MASTODON/CAMEL BONE ENCOUNTERED DURING EXCAVATION
UNRECORDED WASTE

Geosafe Corporation

2950 George Washington Way
Richland, WA 99352
(509) 375-0710
FAX: (509) 375-7721

September 19, 1995

Mr. Jack Prendergast, P.E., DEE
LockHeed-Martin Idaho Technologies
P.O. Box 1625
Idaho Falls, ID 83415

REQUEST FOR INFORMATION ON IN SITU VITRIFICATION (ISV) IN SUPPORT OF A RI/FS FOR THE IDAHO ENGINEERING NATIONAL LABORATORY

Dear Mr. Prendergast:

In response to your September 11, 1995 letter; we are providing information that was requested for a September 19, 1995 deadline. This information has been provided in a question and answer format.

It should be understood that the information you are requesting is somewhat dependent on how ISV will be applied to buried wastes. Two common approaches for applying ISV are: 1) in situ treatment and 2) staged treatment in a waste cell. In situ treatment requires a thorough characterization of wastes before treatment. Characterization needs can be reduced for some sites by pretreating the wastes using some specially developed techniques by Geosafe. Potentially, there are some waste forms that are not suitable for in situ treatment and they should be removed before processing with ISV.

A second approach for applying ISV is to stage the material in a waste cell and then process with ISV. During the staging process, undesirable material can either be pretreated (e.g., crushed or shredded) or removed. Staging of material significantly reduces the amount of up-front characterization that must be done prior to remediation. Based on controlling the placement of material in the treatment cell, the performance of ISV can be estimated very accurately. Many wastes forms that are not suitable for in situ treatment can be treated in a staged configuration if blended with other wastes. The decision as to whether to treat wastes in situ or in a staged configuration is largely an economic consideration. There comes a point at which the cost of restaging material is less expensive than collecting detailed site characterization information.

RESPONSE TO REQUEST FOR INFORMATION

Q1. Is site characteristic data (in addition to that attached) needed in order to determine technology performance? If so, please describe what characterization data is needed.

A1. The following characterization data will be needed to support the detailed evaluation of ISV in the OU 7-13/14 Site Feasibility study: 1) organic content of the wastes, 2) distribution of contaminants in the
waste material, and 3) depth of contamination.

Q2. Will treatability studies be required to obtain performance data for the technology? If so, what is the overall scope for treatability studies?

A2. In general, existing information is available to determine the applicability of ISV to most contaminants and wastes forms. Treatability studies will be required to evaluated the performance of ISV in the detailed analysis phase of the treatability study. The scope of the treatability studies will be depended on whether ISV will be used in situ or in a staged configuration. For either configuration, treatability tests should be performed to evaluate the performance of the off-gas system and durability of the final vitrified product.

Q.3. Will pilot plant or full scale tests be needed to further verify performance data for the technology applied to the INEL OU 7-13/14 site? If so, describe tests needed.

A3. It is not anticipated that pilot plant or full scale tests will be needed to verify the performance of ISV. ISV is a commercially available technology that has been demonstrated on a broad range of contaminants and waste forms. Full scale ISV tests can be conducted in conjunction with an actual remediation, as is the case for the Pit 1 remediation at Oak Ridge.

If you have any questions concerning ISV or need additional information please call me or Mr. Jim Hansen at (509) 375-0710.

Sincerely,

GEOSAFE CORPORATION

Matthew J. Haass

Matthew J. Haass, P.E.
Senior Project & Business Development Engineer

Geosafe Corporation

2950 George Washington Way
Richland, WA 99352
(509) 375-0710
FAX: (509) 375-7721

October 23, 1995

Mr. Jack Prendergast, P.E., DEE
Lockheed-Martin Idaho Technologies
P.O. Box 1625
Idaho Falls, ID 83415

REQUEST FOR INFORMATION ON IN SITU VITRIFICATION (ISV) IN SUPPORT OF A RI/FS FOR THE IDAHO ENGINEERING NATIONAL LABORATORY

Dear Mr. Prendergast:

In response to your September 11, 1995 letter, we are providing the remainder of the information you requested on the ISV technology. A number of the questions on your information request form are difficult to answer completely because of the diversity of the wastes in the RWMC. We have attempted to address all questions as completely as possible given our understanding of the RMWC.

Later this month, I'm planning to attend a pre-proposal meeting at INEL and would welcome the opportunity to meet you. I will give you a call when I know the exact date of this meeting. Until then if you have any questions concerning ISV or need additional information please call me or Mr. Jim Hansen at (509) 375-0710.

Sincerely,

GEOSAFE CORPORATION

Matthew J. Haass

Matthew J. Haass, P.E.
Senior Project & Business Development Engineer

Geosafe
Corporation

2950 George Washington Way
Richland, WA 99352
(509) 375-0710
FAX: (509) 375-7721

January 19, 1996

Mr. Jack Prendergast, P.E., DEE
Lockheed-Martin Idaho Technologies
P.O. Box 1625
Idaho Falls, ID 83415

RESPONSE TO YOUR QUESTIONS ON IN SITU VITRIFICATION (ISV)

Dear Mr. Prendergast:

In response to our recent phone conversation you requested additional information on the following topics: 1) quantify the decision making blocks on the attached Figure 1, 2) provide costing data for ISV pre-treatment technologies and for Geosafe commercial projects and 3) quantify the volume of volatile liquids that can be treated by ISV. Provided below is a discussion of these topics.

1) Quantify the decision making blocks in the first row of the attached Figure 1.

I have attempted to quantify the decision making blocks based on the assumption ISV is being used to process buried wastes. The first block concerning the need for soil addition should not be a problem for most buried waste sites provided sufficient soil is present to form a high quality vitrified product. Treatability studies performed at INEL on simulated buried wastes has demonstrated up to 20 wt% debris can be processed by ISV. Non-combustible debris such as steel and concrete have been successfully processed at much higher loadings, 25 and 75 wt%, respectively.

Void volumes as high as 2.5 cy can be processed with ISV without pretreatment. Larger voids can be processed if they are collapsed by compaction or filled by pressure injection. If void volumes are filled with water, site specific information is needed to determine if soil gas phase permeability to adequate for vapor release.

In general, non-combustible liquids do not present a processing difficulty to ISV if they are not containerized. Liquids that are containerized can be treated by dynamic disruption (vibratory beam penetration). Information on how this technology is implemented is provided in Item 2. Organic liquids do not pose additional operating concerns other than heat generation as discussed in Item 3.

Our ISV treatment system has been designed to process 10 wt% hydrocarbons at full operating power (4 to 6 tons/hr processing rate). Higher hydrocarbon concentrations could be processed by increasing the size of our off-gas cooling system. Combustible solids such as wood and paper have been processed at concentrations up to 30 wt%. Even higher concentrations of combustible materials can be processed by the ISV system at lower processing rates. Organic liquids may cause high heat generation as discussed in Item 3.

2) Provide costing data for ISV pretreatment and Geosafe commercial ISV experience

The pretreatment techniques you've inquired about for ISV include dynamic disruption of sealed containers, pressure injection of solids to fill void spaces, and dynamic compaction to collapse void spaces. The cost estimates prepared for these techniques assume health and safety oversight and special worker training requirements are provide at no cost to the contractor.

Dynamic disruption of containers requires a crane, a vibratory pile driver, one operator and one laborer. The estimated unit cost for dynamic disruption of a burial ground on three foot centers to a 15 ft depth is $2/sf. Pressure injection of solids to fill void spaces is based on pressure grouting rates less a deduction for the cement additive in the grout which is not required. The unit cost for pressure injection of a burial site is estimated to be $100-$140 per cy yard of material treated. The unit cost for dynamic compaction is based on the use of one crane, one operator and one half time laborer. The unit treatment cost for dynamic compaction on 3 ft centers is a$1.50/sf.

Geosafe's commercial ISV treatment costs are based on three commercial projects and are presented in Figure 2. Each of the projects used in compiling this graph had varying site conditions which effected treatment costs. The factors having the greatest influence are the rate of processing and the depth of contamination. Figure 2 shows ISV treatment costs/ton as a function of the rate of processing and the effect of mobilization/ demobilization costs. The figure was based on the application of ISV to hazardous wastes sites and includes all costs associated with treatment, permitting, regulatory compliance and site closure. Geosafe overheads and profit are also included. The application of ISV to DOE sites is expected to have additional costs such as compliance with DOE orders, site specific training requirements and radiation monitoring which have not included in our commercial costs.

3) Quantify the volume of volatile liquids that can be processed with ISV

The volume of volatile liquids that can safely be processed by ISV is a function of the Btu content of the liquid. Geosafe's ISV system has been designed to process liquids containing up to 7 wt% hydrocarbons that have a heat content of 20,000 Btu or less. Higher concentrations of hydrocarbons can be processed by increasing the size of our off-gas treatment system. There is no limit on the aerial size of a saturated soil zone which can be processed with ISV provided the organic loading is acceptable. Sites which exceed the heat removal capacity of our equipment can potentially be pretreated by a technology that lowers organic concentrations to acceptable levels for ISV processing.

I look forward to meeting you on my planned visit to INEL during the week of March 4, 1996. Until then if you have any questions, please call me or Mr. Jim Hansen at (509) 375-0710.

Sincerely,

GEOSAFE CORPORATION

Matthew J. Haass

Matthew J. Haass, P.E.
Senior Project & Business Development Engineer

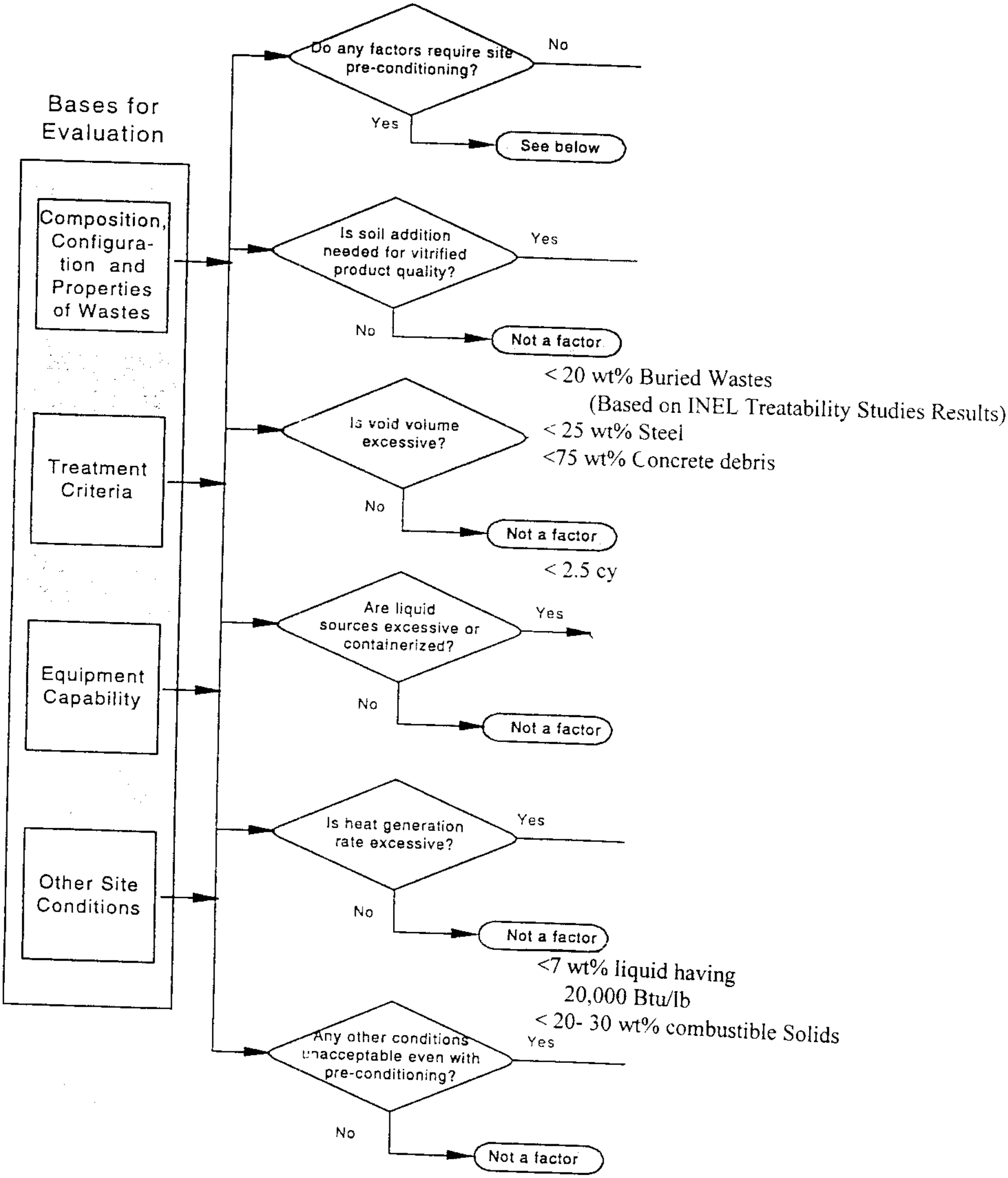


Figure 1: Revision to Site Pre-Conditioning Logic Diagram

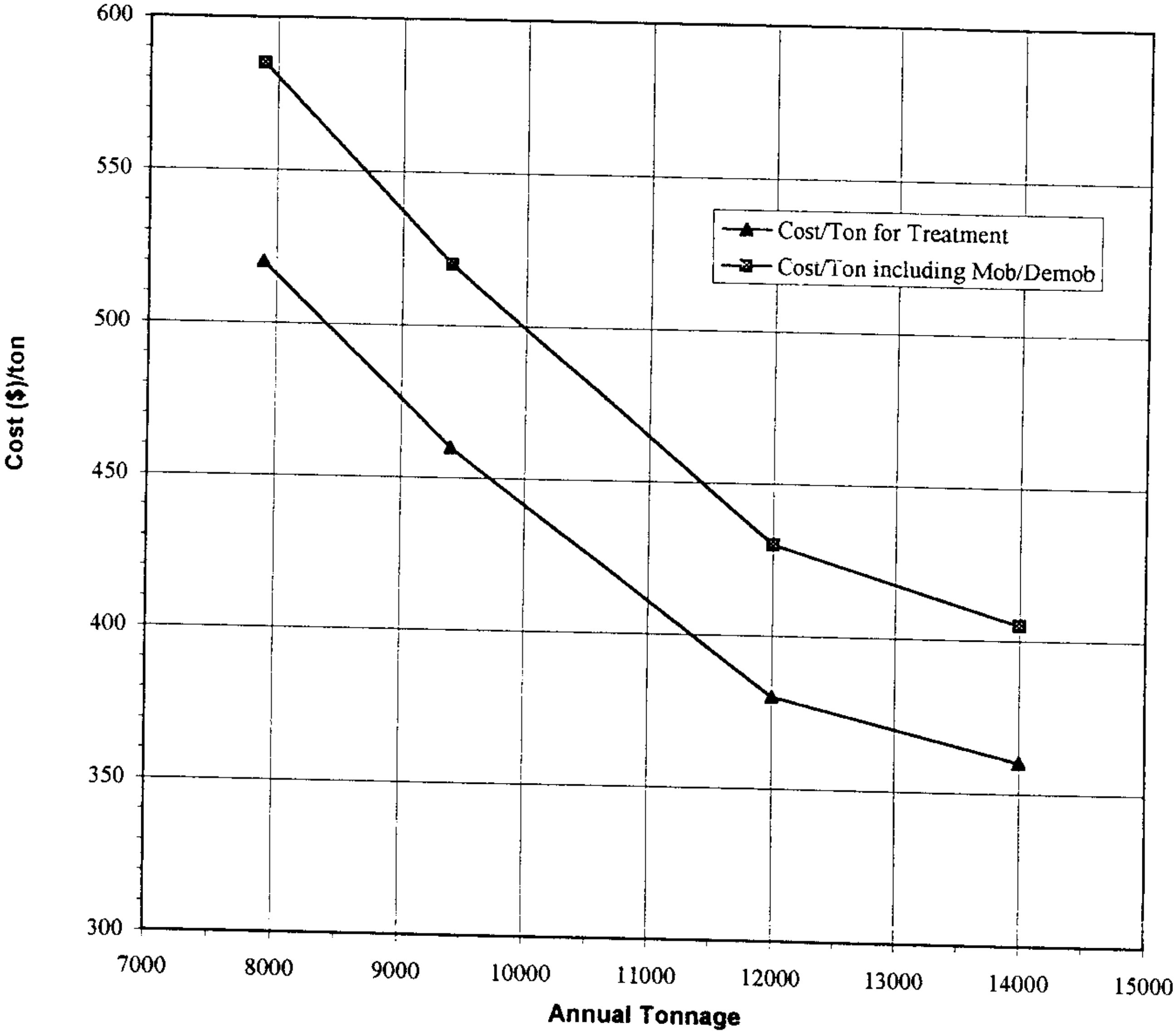


Figure 2: Geosafe Commercial ISV Treatment Costs

Remediation Technology: In Situ Vitrification (ISV)

Project Title: Parsons Chemical Superfund Site

Location: Grand Ledge, Michigan

Scope of Work: The Parsons Chemical Superfund remediation required the treatment of 4,800 tons of contaminated soil with ISV. The soil treated was a silty clay soil containing pesticides (DDT, dieldrin, aldrin, and chlordane), heavy metals (mercury, lead, and arsenic) and trace amounts of dioxins. The contaminated soil was located at various locations on the site and in a drainage ditch about 1/4 mile from the site. To facilitate the melting process, the contaminated soil was excavated and consolidated into nine cells in a 16 ft-deep treatment trench located in a large open area at the site; each cell was 26 ft square. A significant amount of debris from the site (including protective clothing, plastic sheeting, drum lids, and tires) was placed in the cells for treatment. This site contained a perched water table located 8 to 10 ft below grade in the soil adjacent to the treatment cells. To minimize the inflow of groundwater into the treatment trench, an intercept trench was installed to divert groundwater to collection sumps.

Large amounts of environmental sampling data were acquired during this project. Sampling results verified that ISV treatment of the contaminated materials met or exceeded all cleanup requirements and related ARARs. The EPA SITE Program monitored the sixth of eight melts. Results from EPA sampling showed emission levels specified for chlordane, 4,4-DDT, dieldrin and mercury were all met. Vitrified material collected from the site was subjected to TCLP analysis for mercury and pesticides. The test results showed the leachable mercury was well below the regulatory guidelines, and no target pesticides were detected in the leachate. Full details of the SITE Program data acquisition and evaluation are presented in the Geosafe Corporation In Situ Vitrification - Innovative Technology Evaluation Report (EPA/540/R-949520).

Time of Performance: June 15, 1993 to May 27, 1994 (From mobilization to demobilization).

Client: U.S. EPA Region 5
77 West Jackson Blvd. HSE-5J
Chicago, IL 60604

Contact: Mr. Len Zintak, EPA Project Manager (312) 886-4246

Remediation Technology: In Situ Vitrification (ISV)

Project Title: Transformer Service Facility

Location: Spokane, Washington

Scope of Work: This project was conducted under a Demonstration Permit issued by EPA's Office of Toxic Substances as part of an application for a National TSCA Operating Permit for the treatment of PCB-contaminated wastes. This project involved the treatment of 3,500 tons of PCB-contaminated soil and debris staged in 5 treatment cells. One cell contained three zones of soil that had been spiked with PCBs to an average level of 12,000 ppm (17,000 ppm peak). The other four cells contained PCBs at lower levels (140-ppm average) and varying amounts and types of debris including sealed drums containing water. One cell contained 8 wt% concrete debris, and another contained 11 wt% asphalt. To prevent uncontrolled release of water vapor during processing, the drums were punctured prior to ISV treatment using a vibratory beam technique. All five treatment cells were processed without difficulty.

To evaluate the performance of the ISV process for treatment of PCBs, the sampling and analysis plan included acquisition of off-gas emission, secondary waste (scrubber solution and filters), vitrified product, decontamination wipes, and adjacent soil samples. Analyses of the off-gases for PCBs and dioxins/furans were found to be below EPA approved detection limits. Analysis of the vitrified product also confirmed the expected results of non-detect for all organic species (PCBs, dioxins/furans, and PAHs). Adjacent soil sample results confirmed that ISV processing did not result in contamination of adjacent soils, but in fact reduced pre-existing contamination levels in the soil. EPA has prepared a National TSCA Operating Permit for ISV treatment of PCBs; the permit is expected to be issued in October, 1995.

Time of Performance: July 5, 1994 to October 31, 1994 (From mobilization to demobilization).

Client: Bechtel Environmental
50 Beale St.
San Francisco, CA 94116

Contact: Mr. Russ Stenzel, Bechtel Project Manager (415) 768-3385

Remediation Technology: In Situ Vitrification (ISV)

Project Title: Wasatch Chemical Superfund Site

Location: Salt Lake City, Utah

Scope of Work: This ongoing remediation project involves the treatment of 6,000 tons of soil, sludges and debris. The primary contaminants include: dioxin, pentachlorophenol, xylene, chlordane, DDT, DDE, 2,4-D, and TCE. In 1980, contaminated soil from the site was placed in a 125 ft square by 4 ft deep concrete lined evaporation pond to minimize the spread of contamination. Prior to beginning treatment, other soil and debris from the site was gathered and staged on top of the pond for treatment. This debris included: plastic sheeting, wood, pieces of clay pipe, bags and boxes of investigation derived wastes. Following the staging of the debris, a clean soil cover layer was placed over the pond bringing the total treatment depth to 7 ft. The groundwater table at this site varies seasonally but is generally near the elevation of the floor of the evaporation pond.

A total of 37 ISV melts are planned to treat the evaporation pond. As of October 1995, 35 of the scheduled melts have been completed. To improve the operating efficiency of this project, two off-gas hoods were used to minimize the amount of down time between melts. Using two hoods allows one hood to be moved and set into position while the other hood is in operation. This project is currently running on schedule and will be completed in November of 1995.

All samples of vitrified product, off-gas emissions, adjacent and beneath-block soil from the site have indicated the complete compliance with regulatory requirements for the site. ISV performance at the site has been most notable in that it involved the treatment of materials for which no other treatment or disposal means was available. The treatment of high levels of dioxin contamination, including liquid dioxins that were sorbed onto soil for treatment, was a first for dioxin treatment worldwide (to our knowledge).

ATTACHMENT 3 - REQUESTED INFORMATION FOR TECHNOLOGY

Technology Trade Name: In situ Vitrification

Company (Vendor) Name: Geosafe Corporation

Company Address: 2950 George Washington Way, Richland, WA 99352

Contact Person(s): Messrs. James Hansen or Matthew Haass

Phone Number(s): (509) 375-0710

FAX Number(s): (509) 375-7721

Electronic Mail ID(s): geosafe@oneworld.owt.com

Nonproprietary description:

In Situ Vitrification (ISV) is a demonstrated technology for the treatment of earthen materials, (e.g., soil, sludge, tailings, sediment) contaminated with hazardous, mixed, and radioactive materials and debris (e.g., concrete, asphalt, scrap metal, rock, vegetation, wood, plastics, etc.). ISV is one of the few technologies available that can simultaneously treat organic, inorganic and radioactive contaminants in one processing step. ISV destroys most organic and some inorganic compounds by thermally induced decomposition (pyrolysis) in the oxygen-depleted environment in and around the melt zone. Pyrolyzed compounds are typically broken down to their elemental components (carbon, hydrogen, chlorine, etc.). Volatile components travel to the surface of the melt where nearly all are oxidized; any remaining volatile components are treated by the off-gas treatment system. Contaminants that remain in the molten soil (typically metal oxides) are incorporated into a leach resistant vitrified product.

The ISV process works by melting an earthen media (e.g., soil) in place using electricity applied through four graphite electrodes. The electrodes are vertically inserted a short distance into the material to be treated and a highly conductive mixture of graphite frit and glass is spread on the surface between the electrodes. When electricity is applied to the electrodes, the graphite heats up and the glass frit melts at a temperature in excess of 1400° C which causes the surrounding soil to melt. Once soil is in a molten state, it too becomes electrically conductive thereby allowing the melt to grow. After the melt is fully established, it will move downward and outward through the contaminated soil at a rate of 4 to 6 tons per hour.

<u>Description of ISV System</u>

The ISV treatment system consists of an off-gas collection hood, an off-gas treatment system and a power delivery system. All equipment can be moved in three over the road trailers. The off-gas hood is used to collect emissions escaping from the surface of the melt and to support the graphite electrodes used in the melting process. The hood is composed of a structural steel frame which supports a domed shaped cover that completely encloses the melt area. The domed cover is constructed of corrosion resistant steel panels. Four openings for the graphite electrodes are located in the center portion of the hood. The electrodes are vertically inserted through the openings which can be spaced up to 18 ft apart in a square configuration. The off-gas hood is maintained under a constant vacuum to prevent the escape of emissions. Emissions drawn from the hood are piped to the off-gas system for treatment.

The off-gas treatment system is composed of a quencher, scrubber, demister, heater, HEPA filter, activated carbon absorber and an optional thermal oxidation unit. The qencher is used to lower the temperature of the gas stream for off-gas scrubbing. Off-gas scrubbing is used to remove acid and other gases and large particulates. Following scrubbing, the off-gas stream is dewatered and reheated to prevent wetting of the particulate filters. Next it is filtered to remove fine particulates and polished to remove trace organics with either an activated carbon absorber or a thermal oxidation unit.

A specially designed power transformer is used to provide electricity at the appropriate voltage and amperage to the graphite electrodes. The entire vitrification system is monitored from a process control room located in the off-gas trailer. The process control room monitors the following off-gas parameters: oxygen, carbon monoxide, and total hydrocarbons; and following process related parameters: electrode power consumption, off-gas hood temperature, hood vacuum pressure, and other parameters related to the off-gas treatment system.

Applicability to OU7-13/14 waste:

1. *Based on the attached waste/soil description (Attachment 2), are there waste forms or types that could not be treated by your technology? If so please list.*

A general limitation of the ISV technology for treating buried wastes is that the material must be sufficiently characterized to ensure safe operation of the equipment. For example, ISV would not be recommended to process a burial trench if its contents were totally unknown. Specific waste form limitations for ISV are: (1) wastes must contain sufficient earthen material to form a satisfactory vitrified product, (2) sealed containers must be punctured, (3) large internal voids spaces in the waste material must be collapsed or filled, and (4) the aggregate materials should contain less than 10 wt% organics.

The following pre-conditioning methods can be used to make buried wastes acceptable for ISV processing if the above limitations are not met. Sealed containers can be punctured with a steel beam that is vibrated into the ground. The vibrating beam will disrupt the integrity of containers thus making them acceptable for processing. Large void cavities can be filled with sand, grout or concrete or compacted to eliminate void space. Wastes which exceed the organic concentration limit may be processed if blended with other material or if modifications are made to the ISV processing equipment to increase its heat handling capacity.

2. Based on the attached waste/soil description (Attachment 2), are there pretreatment requirements such as sorting, sizing, separations, etc. in order to effectively utilize your technology to treat OU7-13/14 waste? If so please describe.

As discussed above, the primary limitation of the ISV technology for treating buried wastes are sealed containers holding liquids. Burial trenches which have sealed containers of liquids can be pretreated by either puncturing the containers in situ or by excavating the containers and then restaging them. During the restaging process, the containers can be compacted by heavy equipment. Some large buried wastes (e.g., reactor core and other miscellaneous vehicles) may not be acceptable for ISV and need to be removed or size reduced before processing.

3. Has your technology been used to remediate radioactive waste sites? If so, what are typical worker exposure rates? If not, please state how adaptable the technology would be to a radiation environment (feasibility of remote operation, reliability, maintenance requirements, etc.).

In 1983 Pacific Northwest Laboratories performed a pilot-scale test on plutonium contaminated soil that showed excellent results. Between 1986 and 1990 two large-scale ISV radioactive tests were performed at Hanford. The first test treated a portion of a TRU-contaminated drain field. This test was largely, successful; however, some equipment difficulties were encountered. The second test was conducted on a disposal crib (116-B-6A) which contained 1 curie of mixed fission products. This test showed no reportable worker exposure was encountered.

In November 1995, ISV is scheduled to treat a liquid disposal pit at Oak Ridge National Laboratory (Pit 1) which contains 10 curies of strontium and cesium. Geosafe completed intermediate-scale tests (4 to 6 ton melts) in October 1995 at the Marilinga Site in Australia. These tests demonstrated the effectiveness of ISV in treating uranium and plutonium in a complex soil mixture containing up to 37 wt% scrap metal.

ISV should be capable of processing material having a high associated radiation dose because of the following features:

- requires minimal or no material handling
- soil can be placed over a site to provide shielding
- equipment is remotely operated during the melting process

In addition, many of the operation and maintenance items associated with the off-gas treatment system can be performed in a glove-box type enclosure which lessens worker exposures.

ATTACHMENT 3 - REQUESTED INFORMATION FOR TECHNOLOGY

Example destruction efficiencies, including PCB's:

1. ISV has been demonstrated to be capable of achieving better than six-9's DRE during the treatment of PCBs, dioxins. Geosafe Corporation is in the process of receiving a National TSCA permit for the treatment of PCB's up to 17,000 ppm (permit is expected in October, 1995). Geosafe has extensive off-gas sampling results in support of regulatory emission requirements that demonstrate excellent DRE's for a variety of organic compounds, and the ability to comply with state and federal air emission standards.

2. Effectiveness in contaminant immobilization.

ISV is effective in immobilizing most inorganic contaminants. Some portion of volatile and semi-volatile metals (e.g., Hg, Ni, and Cd) may be released into the off-gas treatment stream during processing. These metals can be removed from the off-gas stream by a combination of off-gas scrubbing, HEPA filtration and if required carbon adsorption. Volatile radionuclides such as Cs-137, C-14, Cl-36 and I-129 may require additional processing steps to be removed from the off-gas stream. ISV is effective in thermally destroying reducing agents such as ammonia and hydrazine. ISV has also been demonstrated to be effective in destroying nitrates without producing NOx's in the off-gas stream which are subject to strict regulatory control.

The ISV residual vitrified product has outstanding physical, weathering, and chemical properties. It is typically 5 to 10 times stronger than concrete. It is unaffected by wet/dry and freeze/thaw cycling. It is totally free of organic content, and it typically far surpasses TCLP leach testing criteria as a measure of heavy metal immobilization efficiency. In addition, the product consistency test (PCT) which was developed for evaluating high level waste glass, shows that the ISV vitrified product surpasses melter based glasses for immobilization performance.

Design features to minimize final wastes volumes (gaseous, liquid, solid wastes):

Most secondary wastes (scrubber sludge, HEPA filters and protective equipment) generated by the ISV process can be recycled to future melts. Secondary wastes which cannot be recycled will be shipped to an appropriate waste treatment or disposal facility.

Commercial Capacity Range:

A single ISV system is capable of processing approximately 20,000 tons of material per year based on an 80 percent online efficiency. Geosafe Corporation presently has one commercial ISV system and will be adding additional systems as required to meet market demands. The U.S. DOE also owns an ISV system which is currently being operated by Pacific Northwest Laboratory (PNL) for a demonstration at the Oak Ridge National Laboratory. This system potentially could be made available for use at other DOE Sites.

ATTACHMENT 3 - REQUESTED INFORMATION FOR TECHNOLOGY

Representative Project (Commercial, pilot or demonstration:

Reference Attachment A for three project descriptions.

Development Plans:

Geosafe is currently performing intermediate-scale ISV tests (4-6 tons) on uranium- and plutonium-contaminated wastes (mixed TRU wastes) at the Maralinga Site in Australia. Upon completion of the intermediate-scale tests, Geosafe will be designing a new full-scale system for remediating 21 burial pits at the site. PNL is currently testing a new off-gas treatment hood at ORNL that is designed to lower worker exposures levels when processing radioactive wastes.

Major Utility Requirements:

1) ISV requires a 12.8 or 13.2 KV power line capable of suppling 5 mega-watts of power.

Costs:

Typical treatment costs for ISV are approximately $400 per ton for hazardous wastes and up to $800 to $1,000 per ton for low-level and mixed wastes, respectively. These unit prices exclude mobilization and demobilization costs which are estimated to be $500K (combined total). Once an ISV system has been mobilized at a DOE site, subsequent mobilization cost are in the range of $50 to 100K for each additional operable unit treated at the site.

APPENDIX E

Application of In Situ Vitrification to Buried Wastes, Geosafe Corporation, April 1995

APPLICATION OF IN SITU VITRIFICATION TO BURIED WASTES

Geosafe Corporation
April, 1995

SUMMARY

Geosafe Corporation's In Situ Vitrification (ISV) technology is an onsite thermal treatment technology for the treatment of soils and waste materials containing hazardous, radioactive, and mixed contaminants. The process involves the electric melting of soil or other earthen-like materials at very high temperatures, typically in the range of 1,600-2,000 C. Contaminants and waste materials exposed to the processing conditions are destroyed, removed, and/or permanently immobilized in a high integrity vitrified product.

The ISV process may be applied to the treatment of waste materials that are buried in or intermixed with soil or other earthen-like materials, within appropriate limits. The comparative benefits of ISV relative to other buried waste treatment alternatives include: 1) maximum treatment effectiveness of organic and inorganic contaminants, 2) unequalled immobilization efficiency of heavy metal contaminants, 3) maximum volume reduction (typically 20-50% for soils, and 50-80% for buried wastes), 4) unequalled cost effectiveness (for comparable treatment), and 5) public, occupational, and environmental safety benefits associated with onsite and in situ treatment.

Whereas typical soil treatment applications involve fairly steady state processing conditions, buried waste applications hold the potential to cause transient processing conditions such as varying off-gas evolution rates and off-gas heat loadings that may be undersirable for a variety of reasons. Such applications may require that pre-conditioning measures be performed on the wastes, prior to ISV processing, to avoid or minimize the transient conditions. Site conditions that may warrant pre-conditioning include: 1) need for soil addition to enable attainment of a suitable vitrified product, 2) excessive void space present in the treatment volume, 3) excessive liquid quantities within the treatment volume or liquids in sealed containers, 4) excessive heat generation related to the pyrolysis of waste materials and the oxidation of pyrolysis products, and 5) significant uncertainty, and related hazards, regarding the materials and conditions present within the treatment volume. Such conditions may render ISV processing impracticable for a variety of technical, economic, and safety reasons. In most cases engineering means are available to address these concerns, and to pre-condition the treatment volume for acceptable ISV processing. The primary engineering means include: 1) addition of chemically-appropriate soil on the surface above the waste materials, 2) modification of geochemistry by pressure injection of soil or other earthen-like materials within the treatment volume, 3) compaction of the treatment volume by the "dynamic compaction" method, 4) compaction by the "dynamic disruption" method, 5) removal of liquids by thermally-assisted vacuum extraction processing, 6) removal of void volumes by solids injection, and 7) excavation, removal of unacceptable materials, and restaging of the wastes in a manner acceptable for processing. Through the use of such pre-conditioning methods, the benefits of ISV application to buried wastes may be realized.

I. INTRODUCTION

This paper discusses the possible application of ISV to the treatment of buried waste materials such as may be found in common landfills and specially engineered hazardous and radioactive waste disposal trenches. The paper first presents a brief description of the ISV technology as a basis for understanding the challenges that may be posed to the technology by buried waste treatment applications. Each type of challenge is then discussed in detail, including preferred engineering means to overcome the challenge. The implementability of the preferred pre-conditioning means is then discussed.

ISV is an innovative on site and in situ treatment process that involves the electric melting of contaminated-soil and/or other earthen materials for purposes of permanently destroying, removing, and/or immobilizing hazardous and radioactive contaminants. ISV was invented by Battelle, Pacific Northwest Laboratories in 1980 for the U.S. Department of Energy. More than 200 developmental tests and demonstrations of the technology have been performed since that time at four scales: bench, engineering, pilot, and large-scale.

The process involves forming a melt at the surface of a treatment zone between four electrodes. The molten soil serves as the heating element of the process, wherein electrical energy is directly converted to heat as it passes between the electrodes. Continued application of energy results in the melt growing deeper and wider until the desired treatment volume has been encompassed. When electrical power is shut off, the molten mass solidifies into a vitrified monolith with unequalled physical, chemical, and weathering properties compared to alternative solidification/stabilization technologies.

ISV melting typically involves molten soil temperatures in the range of 1600-2000 C. A steep thermal gradient exists in the soil adjacent to the melt. Soil moisture and other vaporizable materials typically vaporize and move to the surface within the dry zone immediately adjacent the melt. The dry zone is that volume of soil present between the fused soil on the melt side, and the 100 C isotherm on the side away from the melt. This zone has maximum gas-phase permeability relative to other pathways, and is the predominant pathway for release of vapors to the surface. Some amount of vapors may also enter and pass through the melt by penetration through the fusion zone between the melt and the unmelted soil. Vapors may move through this pathway if there is inadequate permeability within the dry zone, or if the vapors are introduced directly into the melt (e.g., as from a sealed container).

The high processing temperature results in the removal of organics from the treatment volume by vaporization followed by pyrolyzation within the dry zone. No organics remain in the melt or the vitrified monolith due to the inability of organics to exist at the temperatures involved. A broad range of organic contaminant types have been successfully treated in various ISV tests and demonstrations, including volatiles (e.g., benzene), semivolatiles (e.g., pesticides), and nonvolatile organics (e.g., PCBs, dioxin).

The predominant disposition of heavy metal oxides during ISV processing involves physical and chemical incorporation into the vitrified product, which produces a permanent immobilization result. Most species of metals remain as oxides in the melt and are incorporated into the vitrified product upon cooling. However, since ferrous metals do not have a strong affinity for oxygen in an ISV melt, they will remain in a reduced state. Therefore, ferrous metals (e.g., scrap metals, piping, drums) present in the treatment zone typically melt and sink to the bottom of the melt pool where they are encapsulated there by the vitrified product. It should be noted that ISV processes both organic and heavy metal (including radioactive) contaminants simultaneously, which is a capability largely limited to vitrification processes.

ISV is also distinguished by its ability to tolerate waste and debris within the treatment zone. Organic debris materials behave as other organics during ISV processing ... they are destroyed primarily by pyrolysis. Inorganic debris materials are typically incorporated into the melt and the resulting vitrified product. Types of debris previously processed by ISV include: vegetation, wood, plastic, rubber, cardboard, paper, protective clothing, HEPA filters, activated carbon filters, drums, concrete, asphalt, tires, scrap metal, and general construction demolition debris.

It should be noted that the ISV development program and Geosafe's commercial operation of the technology have involved large amounts of debris and waste materials in conjunction with contaminated soil applications. For example, individual large-scale melts have been performed that contained 100,000 lbs of concrete and 130,000 lbs of asphalt, as many as 21 large drums in close arrays, large amounts of construction site debris and garbage, and similar conditions. The ISV technology has been demonstrated to be fully capable of treating such materials.

ISV results in a 25-50% volume reduction for most soils, and even greater volume reduction for sludges and wastes that dewater and/or decompose during processing, or that have been disposed in a low density manner. The volume reduction results in creation of a subsidence volume above the vitrified monolith. In most hazardous chemical applications, the subsidence volume is filled with clean soil and the monolith is left in the ground since it is no longer hazardous. With the exception of sites containing gamma or hard beta radiation emitters, sites treated by ISV should be capable of future use without restriction associated with the vitrified monolith.

The commercial large-scale ISV equipment system includes an off-gas containment hood; a quencher; a two-stage, high efficiency wet scrubber that removes particulates and neutralizes acidic gases; high efficiency air filtration; and thermal oxidation as a final polishing step. The configuration of the off-gas treatment system can be modified to address site specific requirements. A basic schematic of the equipment system is illustrated in Figure 1.

The basic ISV technology can be applied in four basic configurations, including: 1) <u>in situ</u>, wherein the contaminated materials are treated where they presently exist in the ground, 2) <u>staged in situ</u>, wherein contaminated materials are partially or completely consolidated or relocated to a special place for treatment, above, below, or partially below grade, 3) <u>stationary batch</u>, wherein materials are melted in one location, the vitrified product is removed after treatment, and the cycle is repeated over and over, and 4) <u>stationary continuous</u>, wherein processing is performed in one location with materials being continuously fed to the melting zone and treated molten material being continuously removed. Figure 2 illustrates these configurations. It should be noted that the first two configurations above involve leaving the melts in place and moving the equipment between melts to treat large areas. The last two configuration alternatives involve moving the materials to be treated, and removing the vitrified product, while leaving the equipment in a stationary processing location.

II. SPECIAL CONCERNS POSED BY BURIED WASTES, AND ENGINEERING MEANS TO ACCOMMODATE THE CONCERNS

The treatment of buried wastes by ISV differs in a number of ways from the treatment of contaminated soils. Some of these differences hold the potential for challenging the safe and effective application of the process, and therefore, must be addressed accordingly. The primary concerns posed by buried wastes are related to their ability to cause transient processing conditions that can make the process difficult to control. The transient conditions of concern are primarily the rate of off-gas generation, heat loadings within the off-gases, and levels of melt disturbance or agitation.

Site factors that directly influence the possibility of these transient conditions include: 1) need for soil addition, 2) excessive void volume, 3) excessive liquid volumes and/or liquids present in sealed containers, 4) excessive heat generation rates resulting from treatment of the materials, and 5) other conditions that could result in unacceptable process conditions or results.

Whether or not these matters may be of concern for a particular project depends upon four primary sets of factors: 1) the composition, configuration, and properties of the materials to be treated, 2) capabilities of the ISV equipment being employed, 3) the treatment performance criteria for the project, and 4) other related site conditions. In some cases these factors are such that treatment of the buried wastes can be done as and where the wastes currently exist, without pre-conditioning. In most other cases it may be possible to pre-condition the materials to be treated, by way of standard geotechnical methods, to make the materials acceptable for ISV treatment. Lastly, it should be noted that more robust processing equipment and other precautions, such as employment of secondary containment structures during processing, may be employed to accommodate more difficult buried waste sites.

The relationships between these factors and the buried waste concerns are illustrated in Figure 3. Each of the buried waste concern areas are discussed in more detail below.

1. Need for soil addition

In some cases, it may be necessary to add soil of specific oxide composition to the treatment zone in order to obtain the desired melt properties and vitrified product properties. ISV processing results in a monolithic vitrified residual product that immobilizes heavy metal contaminants. If ISV processing is performed on organics-only type applications, the properties of the vitrified product are not usually of concern because there are no organics remaining in it. However, if immobilization of heavy metals or radionuclides is an objective, then the quality of vitrified product is important.

The physical and weathering properties of the vitrified product are dependent upon its chemical composition and cooling history. Geosafe can predict the composition and quality of the residual product by performing chemical oxide analyses on the materials to be treated, and analyzing the specific composition using a computerized geochemical model. In addition, small-scale melt tests and property measurements may be employed to predict vitrified product properties.

Applications involving a relatively large proportion of non-earthen waste materials (e.g., organics, lime sludges) compared to the quantity of soil present may result in a vitrified product with less than desired properties. In such cases, it may be possible to add glass forming materials to the treatment zone to attain the desired vitrified product properties. In most cases, the glass forming materials source can be natural soil materials. Also in most cases, the materials addition can be made on top of the materials to be treated. In such cases, the melt is initiated in the added soil layer, and the desired composition is attained as the target contaminated material is melted and intermixed with the molten surface material.

It may also be possible to overcome composition deficiencies by injecting the materials to be added directly into the treatment volume. This option may be preferred if there are large voids in the treatment volume that should be filled in. It may also be preferred if the materials to be added have a significantly lower melting point than the materials to be treated.

2. Excessive void volume

Large void volumes may be of concern to ISV applications if they hold the potential to drain off a significant quantity of melt, resulting in the loss of electrical continuity between electrodes and the need to shut down and restart the processing. In addition, the soil gas present in large voids may cause undesirable melt agitation if and when passing through the melt. In such cases, compaction of the treatment volume may be employed to reduce the size of, or eliminate, large void volumes.

One method of compaction is known as the "dynamic compaction" method, wherein very large weights are dropped onto the surface of the treatment zone, thereby compacting it. Another method is known as the "dynamic disruption" method wherein an I-beam or similar structural member is vibrated from the surface down through the treatment zone on a spacing that ensures the whole volume has been conditioned. Typically, dynamic disruption can be employed in such a way that a 3 to 5-ft radius of influence exists, and materials present within that zone are very energetically shaken, compacted, and disrupted. Sealed containers within that zone, for instance, will be damaged and lose their sealing integrity. In fact, the vibrating beam can pass right through sealed containers, such as drums.

Both of these methods are possible alternatives for the removal of large void volumes. The dropping weight method has the benefit of being non-intrusive; whereas, the dynamic disruption method is intrusive.

3. Excessive liquid quantities

Large quantities of liquids present within the treatment volume hold the potential to generate vapors at unacceptable rates, resulting in undesirable melt agitation, heat removal from the system, and possible short-term loss of off-gas containment. This concern applies to liquids that are present in such large quantities that they cannot be removed by vaporization at rates that are consistent with the ability of the melt and surrounding dry zone to pass the vapors to the surface without undesirable results. Such liquid sources could be groundwater in the saturated zone or containerized or free waste liquids present within the buried waste.

If groundwater is a concern, standard engineering means may be employed to intercept and divert groundwater, or to lower the groundwater level during ISV treatment. Although somewhat related, such techniques are not considered as pre-conditioning of the buried wastes. Pre-conditioning is primarily intended to accommodate waste liquids that may be present within the site either in the free or containerized states.

The ISV process is capable of treating soils that are supersaturated by liquids, as long as the gas-phase permeability of the surrounding dry zone soil is acceptable for the vapor generation rate involved in the specific application. Figure 4 illustrates the normal pathways for vapor removal during ISV. In most cases involving natural soils, and with soil liquid quantities present within acceptable ranges, these requirements are easily met. However, if there are conditions at the site that could severely limit the gas-phase permeability of the soil (e.g., rapid recharge within the saturated zone), the passage of generated vapors would be through the melt rather than through the dry zone, thus possibly resulting in undesirable melt agitation (see Figure 5).

The case of liquids in sealed containers is illustrated in Figure 6. Typical steel containers (e.g., drums) may become sealed into the fusion zone of a melt such that the vapors formed within the drum will all pass to the surface through the melt. In many cases, such passage of vapors may be acceptable; however, some cases hold the potential to undesireably upset the melt.

ISV may be applied to such cases of excessive liquids in the soil by employing some means to reduce the quantity or concentration of liquids. Of course large pools of liquid may be directly pumped out of the treatment zone. Another alternative is to employ a thermally-assisted vacuum extraction method for liquid removal. Either of these methods may be acceptable pre-conditioning means to allow ISV processing. In the case of sealed containers of liquids, the dynamic disruption process described under 2 above for void removal is preferred. The dynamic disruption process can damage sealed containers sufficiently such that liquids present within the containers can release their vapors directly to the dry zone rather than to the melt as discussed above. Dynamic disruption of sealed containers will also result in release of some liquids to the surrounding soil. If the quantity of liquids is too large, application of thermally-assisted vacuum extraction may be employed after the dynamic disruption step.

4. Excessive heat generation

High concentrations of organics may result in generation of heat loads in excess of the off-gas treatment system's design quenching capability. An excess heat load could cause the equipment to malfunction, or otherwise not meet performance specifications. In addition, excessive heat loads may overheat and damage the off-gas collection hood and treatment equipment.

One method of controlling the rate of heat generation from organic decomposition and oxidation involves controlling the rate of melting and corresponding rate of melt movement through the soil and waste. For buried waste applications that may involve significant void volumes into which molten soil may flow, such void volume should be tightly compacted or filled by injection of solids to provide the degree of melting rate control needed.

Another method of controlling the rate of heat generation is to intermix the high organic-concentration soil with low organic-concentration soil so as to attain an "averaging down" effect on organic concentrations in the soil. In addition, clean soil can be added to help attain acceptable organic concentrations if needed.

5. Other unacceptable conditions

If there remain other unacceptable conditions at a site, even given the pre-conditioning options presented above, then it would be necessary to restage the buried wastes for treatment, including the following steps: 1) excavation, 2) removal of unacceptable materials or conditions, if any, and 3) placement of the remaining materials within the soil in an acceptable manner for ISV processing. Such restaging may be adviseable for cases wherein the site characterization information in inadequate to make acceptable decisions regarding pre-conditioning options. Or, restaging may be advisable if there are potentially explosive materials within the site (e.g., unexploded ordnance, pressurized gases, combustible materials present with oxidizers). Restaging holds the potential to allow treatment of even the most difficult buried waste sites.

Lastly, if restaging is not considered practicable, the buried wastes in question must be judged unsuitable for processing by ISV. In such case, it may be profitable to reconsider the performance criteria that has been established for the evaluation process, or to consider enhanced ISV equipment capabilities that would pass the evaluation.

III. STATUS OF TECHNOLOGY FOR BURIED WASTE APPLICATIONS

The pre-conditioning technologies described above are considered by Geosafe to be state-of-the-art technologies that can be applied today on a commercial basis with a high degree of confidence. The status of each technology is briefly summarized below.

Addition of soil to the surface is a common practice that Geosafe employs for various purposes during its ongoing commercial ISV remediation operations. By selecting the appropriate chemical and physical properties of the additive soil, it is possible to achieve the desired vitrified product properties.

Pressure injection of solids is a common geotechnical engineering practice that is often used for the injection of grout and similar materials. High pressure injection of buried wastes has been demonstrated at DOE's INEL facility by a Westinghouse Hanford geotechnical engineering group. In addition, Battelle/PNL employed this method for filling the crib void volume before performing the ISV demonstration on the 116-B crib.

Dynamic compaction is a common geotechnical engineering practice that is used for compaction of soils. This technology has also been demonstrated by Westinghouse Hanford.

Dynamic disruption is a well understood geotechnical engineering practice that is used for insertion of metal columns or sheeting (plates) into soil for various purposes. Its application to wastes compaction has been demonstrated at DOE's Hanford site by Westinghouse Hanford. Bechtel Environmental performed this method of pre-conditioning at the GE/Spokane site, to disrupt 80 drums containing soil and water, prior to Geosafe's performance of the National TSCA Demonstration project at the site. The method was found to be very effective and reasonable in cost.

Thermally-assisted removal by vapor extraction (VEX) is a well understood method for removal of VOCs and SVOCs from contaminated soil sites. Whereas ambient temperature VEX processes are limited to the removal of the more highly volatile organics from permeable soils, thermal enhancement enables much greater removal rates, removal of organics with higher vaporization temperatures, and application to tighter soils. There are several different methods for heating the soil (e.g., rf-heating, steam injection, hot air injection, resistance heating). Geosafe prefers a Battelle Pacific Northwest Laboratories-developed technology called Six-Phase Soil Heating (SPSH) that is able to work in lower permeability soils than other VEX processes. It is also favored because it provides a more uniform heating pattern and is more controllable. During SPSH, electric current flows through the soil, heating it up and removing the soil moisture. The higher temperature and the flow of water vapor result in effective removal of organics.

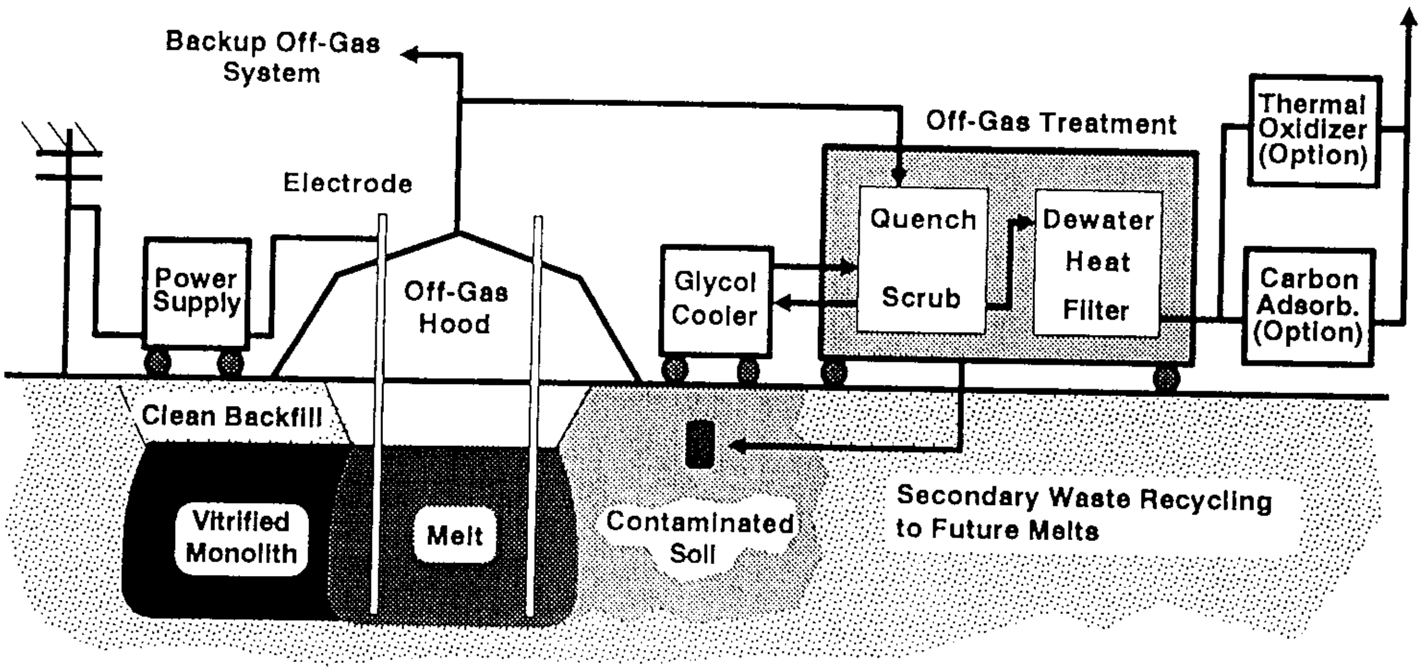
Excavation and restaging employs standard earth-working technologies. Restaging involves controlling the location and concentration of wastes that are co-located within the treatment volume with the soil. Standard compaction methods may be employed to densify the emplaced soil and wastes. Staging has been employed in several of Geosafe's commercial remediation projects.

It is recognized that this option is often considered last due to associated cost and safety issues, particularly for radioactive sites. For these reasons, priority consideration should be given to making a site acceptable for processing by the other non-excavation related pre-conditioning options if possible. In addition, the option of preparing more robust equipment, and operating under secondary containment, may also be preferrable to excavation and restaging.

IV. FOR MORE INFORMATION

A large body of information is available in support of the above discussion. Persons interested in pursuing this subject further are invited to contact Geosafe with specific information requests. Contact Geosafe at (509) 375-0710, or mail requests to 2950 George Washington Way, Richland, WA 99352, attention of James E. Hansen.

FIGURE 1. Overall ISV System Schematic



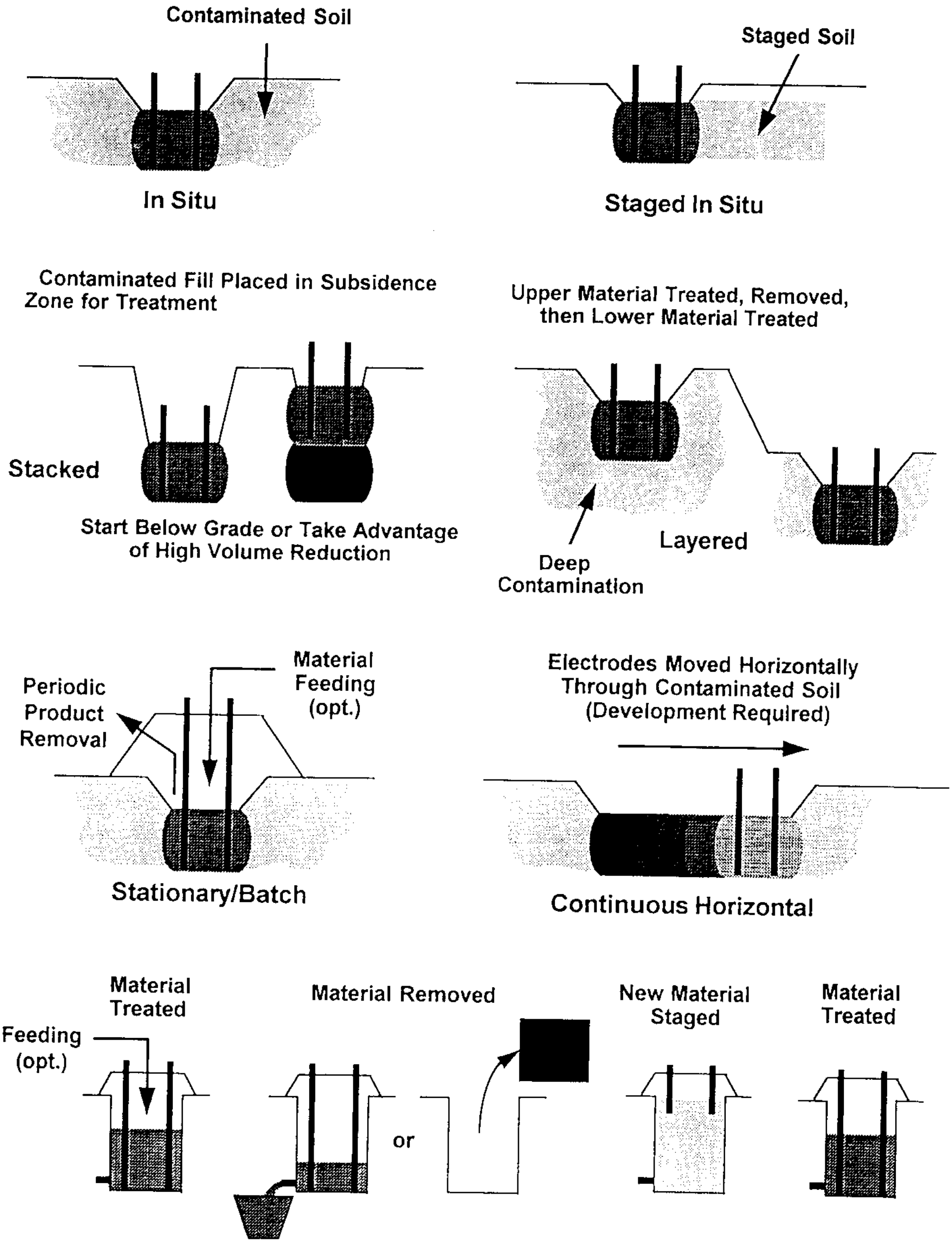


FIGURE 2. Alternative ISV Application Configurations

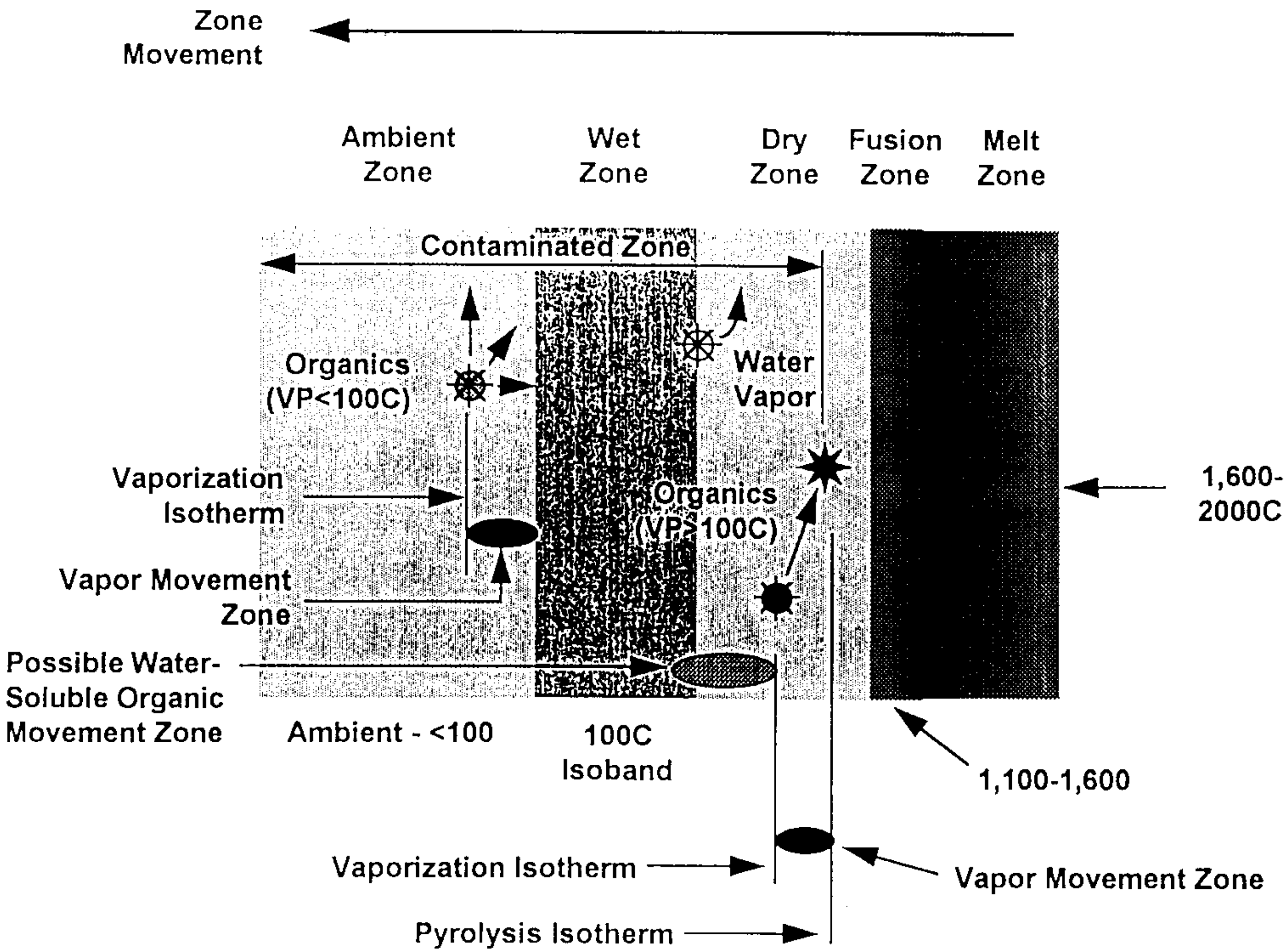


FIGURE 4. Typical Movement of Vapors in Dry Zone Adjacent Melt

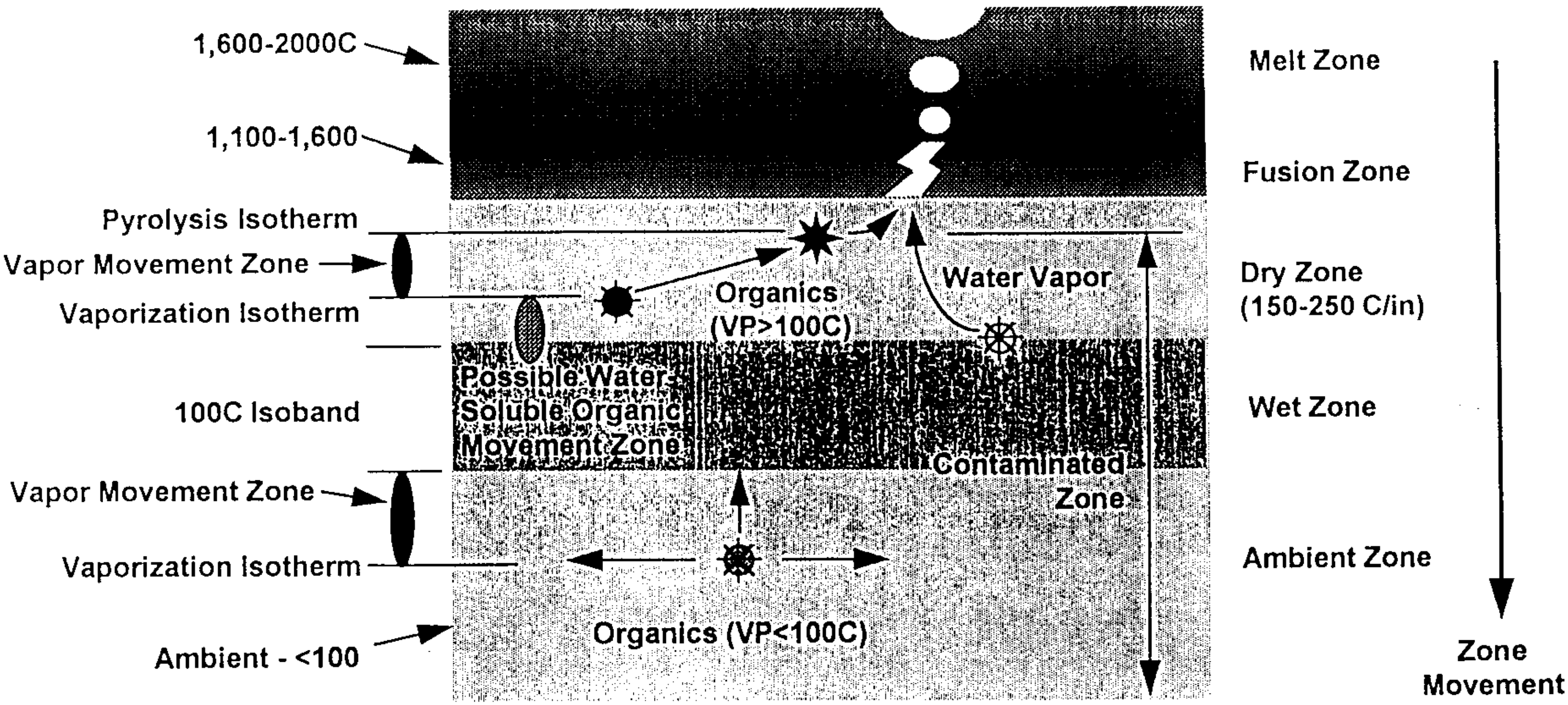


FIGURE 5. Movement of Vapors Through Fusion Zone and Melt

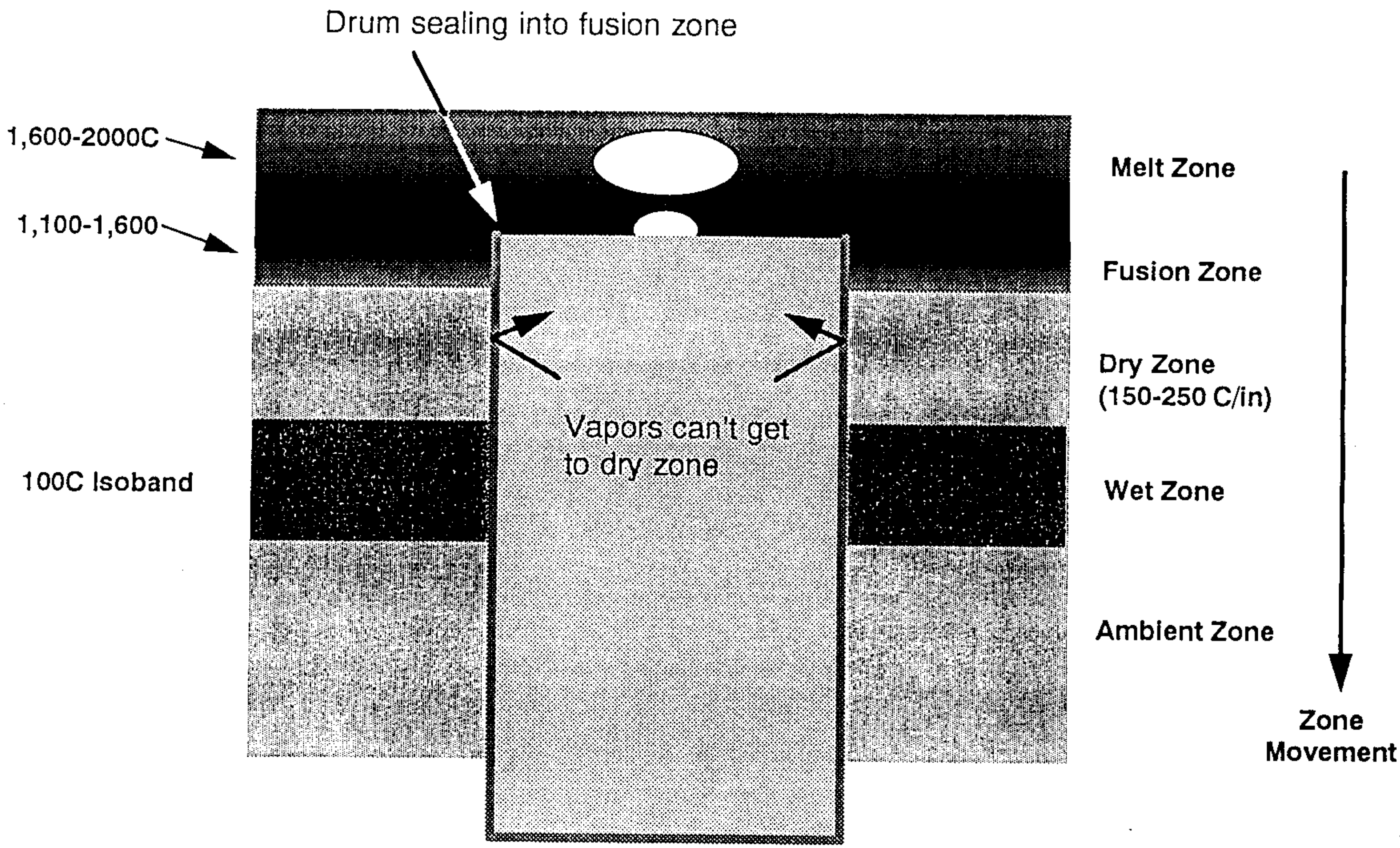


FIGURE 6. Sealing of Drum Containing Liquid into Fusion Zone

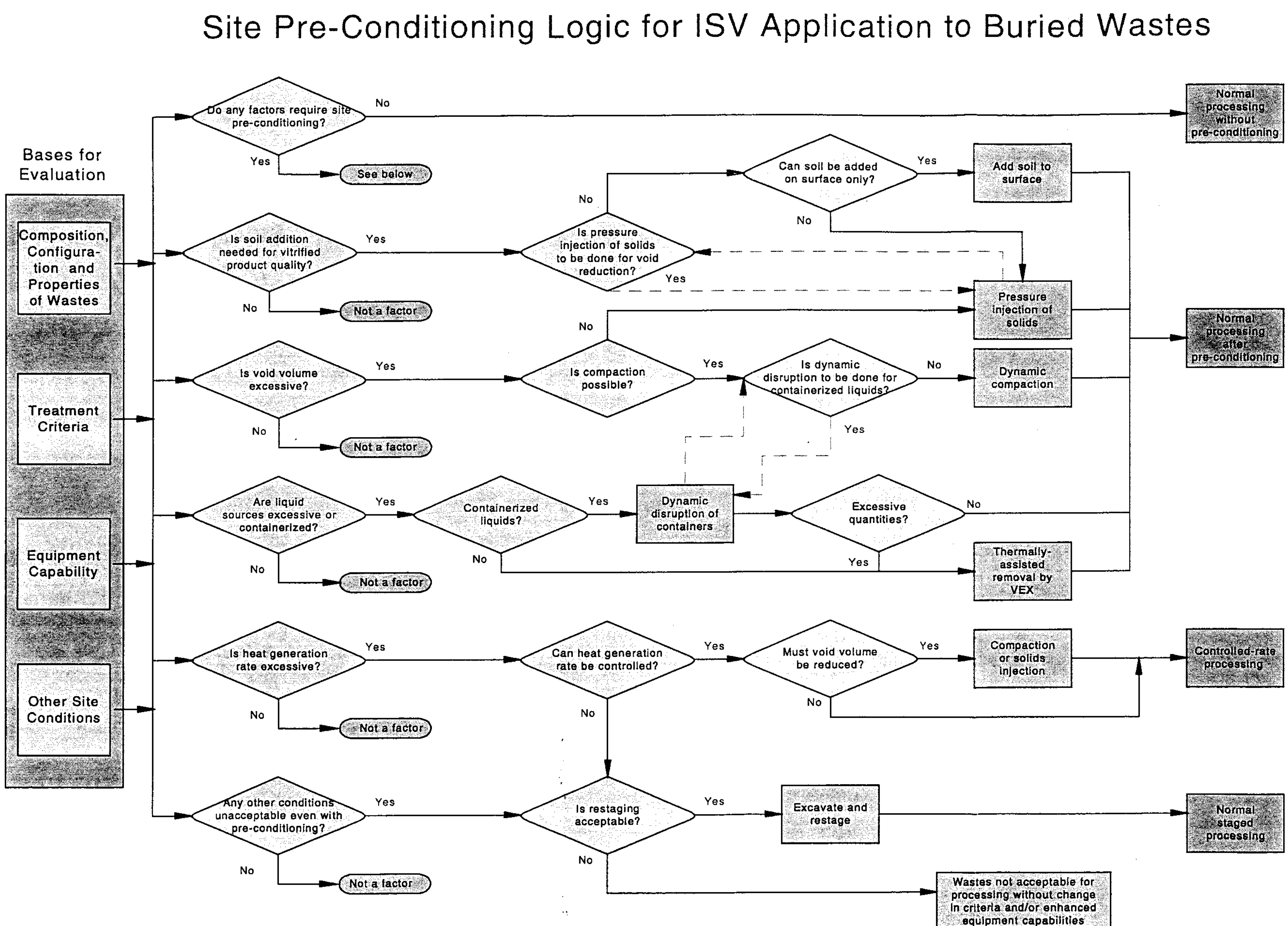


FIGURE 3. Site Pre-Conditioning Logic

4/12/95

APPENDIX F

Miscellaneous Calculations

APPENDIX F

MISCELLANEOUS CALCULATIONS

The calculations shown below deal with In Situ Vitrification cost determinations based upon several sources of information and assumptions which are noted accordingly where applicable.

ISV cost = $\$648/yd^3$ of waste treated. Reference No. 26; Table II-10-1, Preliminary Systems Design Study Assessment Report.

Average Density:

Calculate the average density of buried waste at the Sub-surface Disposal Area (SDA). Reference; Appendix D, Attachment 2, OU 7-13/14 Characterization.

Waste Volume = 6.8×10^6 ft^3; Waste Density = 40 lb/ft^3
Soil Volume = 10×10^6 ft^3; Soil bulk density = 100 lb/ft^3 with avg, moisture content @ 12.3 wt%

Average Density = $[6.8(40) + 10(100)]/16.8 = 75.7\ lb/ft^3$
Average Density = $(75.7\ lb/ft^3) \times (27 ft^3/yd^3) = 2044.3\ lb/yd^3$
Average Density = $(2044.3\ lb/yd^3) \times (1\ ton/2000\ lbs) = 1.022\ tons/yd^3$

ISV Cost:

ISV cost = $(\$648/yd^3) \times (1\ yd^3/1.002\ tons) = \$634/ton$ treated

Pre-conditioning costs:

* Assume an ISV treatment depth of 20 feet at the SDA.

Then the volume of soil represented by one ft^2 of surface area is:
volume = $(20\ ft) \times (1 ft^2) = 20\ ft^3$
volume = $(20\ ft^3) \times (1\ yd^3/27\ ft^3) = 0.7407\ yd^3$

1. **Dynamic Compaction Cost**
   Dynamic Compaction Cost = $(\$1.50/ft^2) / (0.7407\ yd^3/ft^2$ surface area$) = \$2.025/yd^3$

2. **Dynamic Disruption Cost**
   Dynamic Disruption Cost = $(\$2.00/ft^2) / (0.7407\ yd^3/ft^2$ surface area$) = \$2.70/yd^3$

therefore; the cost adders for dynamic compaction and dynamic disruption is:
cost adders total = $(\$2.025 + \$2.70)/yd^3 = \$4.725/yd^3 = \$4.73/yd^3$

ISV cost with dynamic compaction and dynamic disruption is:

ISV cost = $\$648/yd^3 + \$4.73/yd^3 = \$652.73/yd^3 = \$653/yd^3$ approximately

Percent Increase in ISV cost with dynamic compaction and dynamic disruption pre-conditioning is:

% Increase = $(4.73)(100)/(648 + 4.73) = 0.72\%$

Note: This cost increase is almost insignificant.

* Assume that Pressure Injection of Solids is required and that the volume of material treated is the total volume of waste present and that this volume of waste is the amount identified by the Preliminary System Design Study, such that a new life cycle cost can be calculated using the life cycle cost for ISV in the System Design Study Report.

then; the cost cost of treatment will increase by approximately $\$140/yd^3$ as shown below;

New Life Cycle Cost = $[(\$648/yd^3 + \$140/yd^3)/ (\$648/yd^3)] x (\$288x 10^6) = \$350 x 10^6$, and

% Increase in treatment cost = $[(\$140/yd^3) x (100)] / [(\$648/yd^3) + (\$140/yd^3)] = 17.8\%$

3. Percent Increase in Treatment Cost with Pre-conditioning Technologies

New Treatment cost with all pre-conditioning steps included is:

New Treatment Cost = $\$648/yd^3 + \$2.025/yd^3 + \$2.70/yd^3 + \$140/yd^3 = \$792.73/yd^3$

New Life Cycle Cost = $(\$792.73/\$648) x (\$288 x 10^6) = \$352.3 x 10^6$

Percent Increase in Treatment Cost = $[(\$140. + \$4.73)/(\$648. + \$140. + \$4.73)] x (100) = 18.3\%$